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ASSESSMENT OF THE RELATIONSHIP BETWEEN ASYMMETRY IN CEREBRAL HEMISPHERE AROUSAL AND PERCEPTUAL ASYMMETRY

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for

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The research discussed in this research note had for its purpose the examination of this question: is the relative functioning of each cerebral hemisphere's perceptual speed (perceptual asymmetry) related to the relative arousal of each cerebral hemisphere (arousal asymmetry). The results of a lexical decision class (language processing) support Levy's contention that with left hemisphere arousal there is a proportionate increase in right visual field advantage.

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PREFACE

The research described in this report was conducted at the Georgia Tech Research Institute of the Georgia Institute of Technology under the technical supervision of Dr. Joanne Green. The research was performed in the Human Performance Branch of the Concepts Analysis Division of the Systems Engineering Laboratory. The technical representatives for the U.S. Army Research Institute were Dr. Judith Orasanu and Dr. George Lawrence.

The success of the research has depended heavily upon the important contributions of a number of individuals. The project has benefited from steadfast Georgia Tech management support provided by Mr. Robert P. Zimmer, Mr. William E. Sears, III, and Dr. Theodore J. Doll. Invaluable technical assistance was provided by the two consultants who served on the project, Dr. Charles M. Epstein, a neurologist at the Emory University Clinic, and Dr. Robin D. Morris, a neuropsychologist at Georgia State University. Dr. Epstein was influential in designing the approach to recording and analyzing electroencephalogram (EEG) activity. He personally reviewed the EEG data for artifact. Dr. Morris helped to resolve issues related to experimental design, data analysis, and conceptual interpretation. Major contributions to the performance of the experiments and to the collection of EEG data were made by Mr. Peter DeNatale, a graduate student in psychology at Georgia Tech, and Ms. Gail Brickley and Ms. Joan Moore, EEG technicians from the Emory University Hospital. The hardware and software configurations used for experimentation and data analysis benefited significantly from contributions made by Mr. Andrew H. Register and Mr. Michael Cooper, both electrical engineering students at Georgia Tech.

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SECTION I

EXECUTIVE SUMMARY

This report describes basic research which investigated principles of human brain functioning that have implications for better understanding and predicting individual differences in human performance. Although the left and right brain hemispheres interact extensively in determining overall human behavior, each hemisphere has specialized capabilities and operates independently to some extent. Most relevant to the present research is the fact that one hemisphere may be more aroused than the other, a condition described as arousal asymmetry. There is evidence of individual differences in the nature of such arousal asymmetry. Also relevant is the fact that the left hemisphere is specialized for language-related processing. These characteristics have implications for understanding and predicting the nature of individual differences in performance in a variety of military environments. The ultimate goal of the research is to facilitate human performance in the demanding, stressful conditions typical of military environments.

The research is most relevant to understanding individual differences in conditions dependent upon the fast, accurate processing of visual information which appears to the left or right of visual focus, i.e., in peripheral vision. Such conditions are commonly faced by a variety of military operators who perform in rich, complex visual environments. Such environments typically require the monitoring of visual information on a display, or on multiple displays, all of which cannot be simultaneously focused on.

In such conditions, critical visual information may appear to the left or right of the point of visual focus, i.e., in the left or right visual field. Because of the nature of nervous system organization, visual signals appearing in a particular visual field (left or right) are initially received by only one brain hemisphere. Therefore, the characteristics of that hemisphere can affect performance. For example, in language-related tasks, most individuals are faster in response to stimuli presented in the right visual field because such stimuli are initially received by the language-specialized left hemisphere. The present research has implications for approaches to predicting, for individuals, the nature of certain brain characteristics, and, therefore, the relative speed of performance based on left versus right visual field signals.

The present research investigated the hypothesis that individual perceptual asymmetry, the relative speed of performance based on left versus right visual field stimuli, is related to cerebral hemisphere arousal asymmetry, the relative arousal level of the left versus the right hemisphere. This relationship was proposed by Levy, Heller, Banich, and Burton (1983), who also indicated that individual arousal asymmetry may be related to certain other important performance and personality characteristics. The objectives of the present research were as follows:

1. To obtain measures of individual arousal asymmetry during performance of a task associated with individual differences in perceptual asymmetry.

2. To examine the relationship between individual arousal asymmetry and individual perceptual asymmetry.

3. To examine the extent to which individual arousal asymmetry is a stable characteristic.

The research approach used measures of electroencephalographic (EEG) activity to assess individual arousal asymmetry. Individual perceptual asymmetry was assessed by examining the relative speed of responses to stimuli presented in the left versus right visual field during performance of a standard, experimental, cognitive task, the lexical decision task. Arousal asymmetry was recorded during performance of the lexical decision task, as well as during other less demanding conditions both preceding and following this task.

The results of the research generally support the Levy et al. (1983) proposal, and suggest the following conclusions:

1. For the lexical decision task, when arousal asymmetry is measured under certain conditions, the nature of individual arousal asymmetry is related to the nature of individual perceptual asymmetry. For individuals having greater right hemisphere arousal, or little arousal asymmetry, perceptual asymmetry favoring the right visual field was small. Individuals having greater left hemisphere arousal tended to exhibit greater perceptual asymmetry favoring the right visual field.

2. There is some evidence that individual arousal asymmetry is a stable feature that characterizes the individual over time. Certain measurements of arousal asymmetry obtained during conditions either preceding or following the lexical decision task were significantly related both to the arousal asymmetry during the lexical decision task, to each other, and to the perceptual asymmetry during the lexical decision task.

Although the results must be replicated and examined for generalizability before they are applied to practical problems, they have considerable potential for understanding and predicting the nature of individual differences in performance. The results suggest that it may be possible to use measures of arousal asymmetry obtained in relatively simple conditions to predict, for individuals, certain aspects of the quality of performance in subsequent, more complex (and perhaps more important) conditions. More specifically, it may be possible to predict the relative speed of response to stimulus appearing in the left versus right visual field in complex visual environments. Such measurement could be used to select individuals whose characteristic arousal asymmetry is most likely to facilitate performance.

SECTION II

BACKGROUND FOR THE RESEARCH

A. Introduction

The purpose of this section is to describe the basis for the present research. The section begins by reviewing the nature of individual differences in perceptual asymmetry. Theoretical and empirical evidence suggesting a relationship between perceptual asymmetry and hemispheric arousal asymmetry is then reviewed, including hypotheses concerning the nature of this relationship. Finally, the objectives of the research and the rationale for the experimental approach are detailed.

B. Context for the Research

1. Variation in Perceptual Asymmetry

There is a wide variety of performance dimensions along which individuals differ from one another. One of these dimensions is perceptual asymmetry. Perceptual asymmetry is the tendency for performance to be better when a stimulus appears in one lateral location rather than another. For example, if an individual is faster for a given task when the stimulus appears to the left of visual focus, i.e., in the left visual field, this would be described as a perceptual asymmetry favoring the left visual field.

In the present research, interest focused on the nature and magnitude of *individual* visual perceptual asymmetry, i.e., the identity of the visual field (right or left) favored by each individual and the degree to which that visual field is favored. As later discussion will elaborate, individual perceptual asymmetry is of particular interest because it may reflect an individual characteristic which affects a wide range of behaviors.

Perceptual asymmetry is often related to the nature of the task being performed. One of the more reliable patterns is the tendency, especially among right-handed samples, for there to be a perceptual asymmetry favoring right visual field stimuli when language-related tasks are performed. As Figure 1 illustrates, because of the organization of the retinocortical pathways, stimuli occurring in the right visual field, i.e., to the right of visual focus, are projected to the left cerebral hemisphere, while stimuli appearing in the left visual field project to the right cerebral hemisphere. In the great majority of right-handed individuals, the left hemisphere of the brain is better at language-related processing than is the right hemisphere. Therefore, in language-related tasks, one would expect a perceptual asymmetry favoring the right visual field since stimuli occurring in that visual field are projected to the hemisphere more efficient at the required processing. This expectation has been

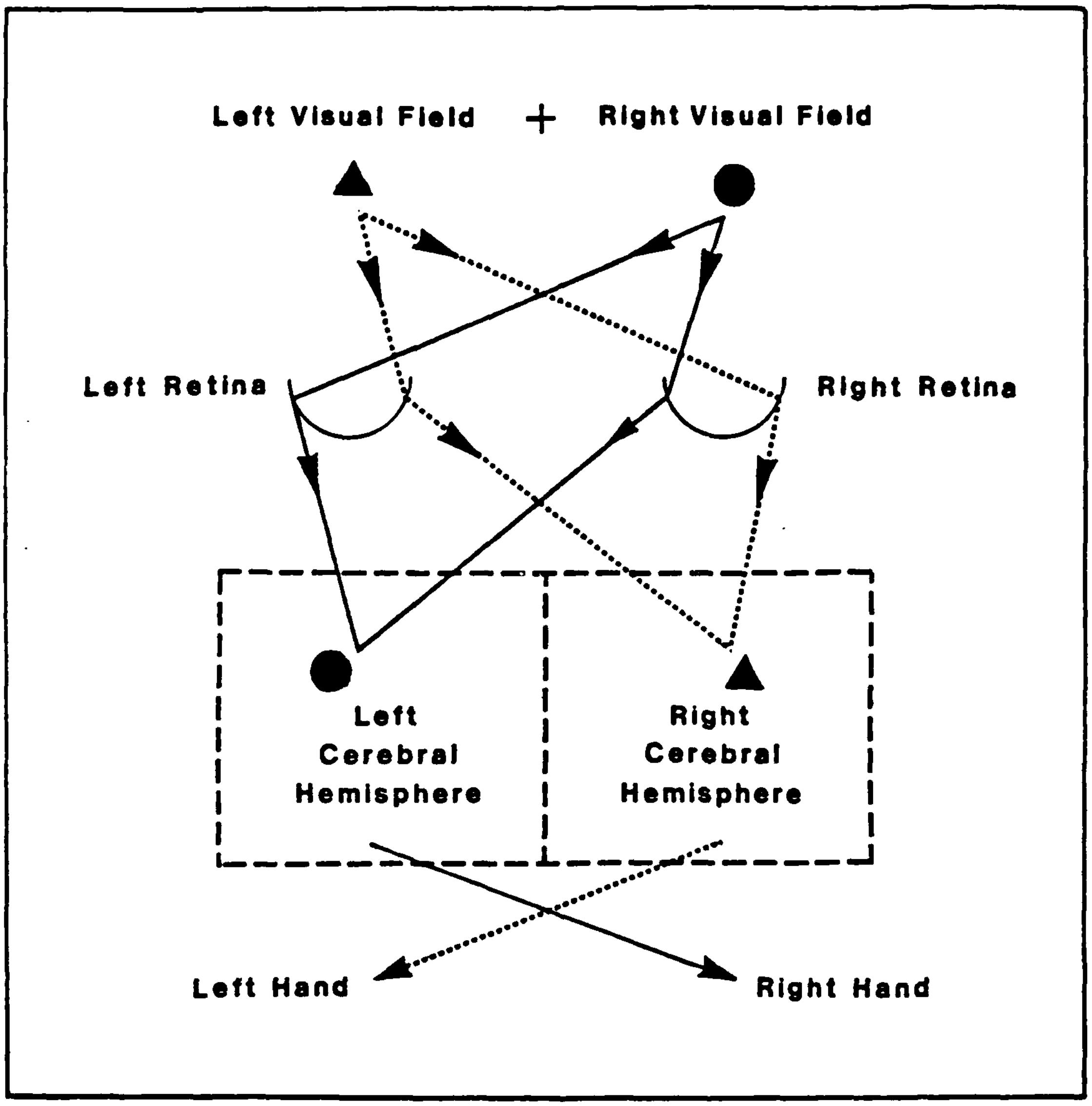

Figure 1. A Schematic Diagram of the Neural Connections to the Cerebral Hemispheres.

confirmed in a number of studies (Bradshaw, Gates, & Nettleton, 1977; Klatzky & Atkinson, 1971).

While statistical tests on group means provide evidence of a significant right visual field advantage, there is considerable inconsistency between individuals in the magnitude and also, sometimes, in the direction of the perceptual asymmetry. In Table 1 are data (Green, 1985) that illustrate this variability. Subjects were right-handed males performing a lexical decision task, a language-related task often used in experimental studies. There is an overall, significant right visual field advantage of 51.2 ms, which is consistent with the performance of a majority of the subjects. However, there is large variation between subjects in the magnitude of the right visual field advantage, with some subjects showing a large advantage (e.g., Subjects 1, 13), some showing essentially no visual field difference (e.g., Subjects 3, 17), and one subject even showing a left visual field advantage (Subject 23).

This between-individual variation is common in studies using a typical experimental population, i.e., "normal" college students. Such variation is typically attributed to error variance or, as Levy, Heller, Banich, and Burton (1983) have pointed out, it is ignored or attributed to individual differences in hemispheric specialization.

The latter explanation implies that among right-handers there is considerable between-individual variation in the degree to which the left hemisphere is specialized for language-related processing. This implication is, however, inconsistent with the results of clinical research on the relationship between the locus of brain injury and the presence of language deficits. Among right-handed individuals, language deficits are almost exclusively associated with injury to the left, rather than to the right, hemisphere. Clinical research of this sort suggests that perhaps ninety nine percent of right-handed individuals have left hemisphere specialization for language functioning. This implies there should be substantial between-individual consistency in perceptual asymmetry during language-related tasks, rather than the variability that is typically observed.

2. Variation in Arousal Asymmetry

One way of explaining the between-individual variation in perceptual asymmetry is to assume that an additional factor is interacting with left hemisphere language specialization in determining the observed asymmetry. Levy, Banich, Burton, and Heller (1983) have proposed that asymmetry in cerebral hemisphere arousal level is an important factor mediating perceptual asymmetry. They propose that, "a large proportion of the variation among right-handed individuals in perceptual asymmetries arises from individual differences in characteristic and task-independent asymmetries of hemispheric arousal." Their proposal is particularly important in that it implies that arousal asymmetry affects not only perceptual asymmetry, but also may be a

TABLE 1

Perceptual Asymmetries of Right-Handed Males During a Lexical Decision Task (Green, 1985). Perceptual asymmetry is median left minus median right visual field reaction time (ms). Positive values indicate a right visual field advantage.

Subject	Perceptual Asymmetry
1	192
2	99
3	8
4	123
5	86
6	55
7	71
8	46
9	39
10	9
11	32
12	56
13	189
14	7
15	17
16	99
17	3
18	74
19	-4
20	7
21	25
22	23
23	-35
24	57
25	3
26	90
27	-1
28	48
29	81
30	9
31	93
32	36
MEAN =	51.2
S.D. =	52.5

fundamental individual characteristic mediating a wide range of individual differences in performance and personality. Levy et al.(1983) review clinical evidence relating unusual arousal asymmetries to depression, mania, and to unusual self-evaluative tendencies.

The purpose of the present research was to examine the proposal of Levy et al. (1983), specifically the hypothesis that there is a relationship between individual hemispheric arousal asymmetry and individual perceptual asymmetry. Their proposal has several important components. First is the idea that there is asymmetry in brain hemisphere arousal. That is, rather than being equivalently aroused, the hemispheres are differentially aroused.

Second, it is proposed that arousal asymmetry confers an advantage to the processing of stimuli in one visual field. Arousal asymmetry will confer an advantage on stimuli appearing in the visual field that projects directly to the more highly aroused hemisphere. This advantage could be related to an attentional bias favoring stimuli in that visual field (Kinsbourne & Hicks, 1978), or to increased receptivity of the more aroused hemisphere.

Third, it is proposed that an individual's arousal asymmetry interacts with left hemisphere language specialization in determining the overall perceptual asymmetry for that individual performing a language-related task. Assuming left hemisphere language specialization, when arousal asymmetry is large, with the left hemisphere being more aroused, the overall perceptual asymmetry favoring the right visual field will also be large.

A fourth component of the hypothesis is that arousal asymmetry is relatively stable within an individual. That is, if arousal asymmetry is measured at several different times, the degree of asymmetry will be fairly consistent for a given person.

Finally, a crucial aspect of the hypothesis is the suggestion that there is variation between individuals in the characteristic degree of arousal asymmetry, and that this is related to the nature of individual perceptual asymmetry. Among individuals having left hemisphere language specialization, those having asymmetrical arousal with higher left hemisphere arousal will exhibit large perceptual asymmetries favoring the right visual field during language-related tasks. In such individuals both hemispheric specialization and arousal asymmetry strongly favor right visual field stimuli. Among individuals having left hemisphere language specialization and nearly symmetrical arousal, perceptual asymmetry favoring right visual field stimuli will be moderate, occurring largely as a function of hemispheric specialization. Among individuals having left hemisphere language specialization and higher right hemisphere arousal, there will be little perceptual asymmetry. This is because the right visual field advantage conferred by hemispheric specialization is counterbalanced by a left visual field advantage associated with higher arousal of the right hemisphere.

Levy et al.(1983) review a range of evidence supporting the various aspects of this theory. Asymmetries in arousal are implied by studies demonstrating asymmetries in dopamine level (Glick, Jerussi, & Zimmerberg, 1977), a neurotransmitter important to maintaining arousal. Studies measuring electroencephalographic (EEG) activity have reported individual differences in asymmetries. Both EEG studies (Erlichman & Weiner, 1979) and blood flow studies (Dabbs & Choo, 1980) have reported high within-subject correlations (0.69-0.74) in measures implying arousal asymmetry. A relationship between arousal asymmetry and perceptual asymmetry is suggested by studies demonstrating that activities which differentially activate one hemisphere (e.g., as language-related tasks activate the left hemisphere) improve performance based on stimuli appearing in the visual field projecting to that hemisphere (Gilbert & Bakan, 1973; Hellige & Cox, 1976).

The notion that perceptual asymmetry may, in part, reflect an arousal asymmetry mediating a variety of individual characteristics is supported by experimental evidence generated by Levy et al. (1983). They used the visual perceptual asymmetry exhibited during a language-related task (syllable identification) to categorize each subject as having either an arousal asymmetry favoring the left hemisphere ("strong asymmetry subjects") or little arousal asymmetry ("weak asymmetry subjects"). Subjects showing a large right visual field advantage were assigned to the strong asymmetry group; those showing little or no right visual field advantage were assigned to the weak asymmetry group.

Differences in the performance of these groups in a variety of conditions were consistent with the idea that the strong asymmetry subjects had a larger arousal asymmetry favoring the left hemisphere. Performance based on right visual field stimuli was more accurate for the strong asymmetry group than for the weak asymmetry group. This is consistent with the idea that the strong asymmetry group had a more aroused left hemisphere. Between-group differences in the affective implications of self-evaluations of performance were consistent with clinical evidence suggesting a role of arousal asymmetry in the regulation of affect and mood (Dagani, 1981; D'Elia & Perris, 1974). Finally, there tended to be an inverse relationship between the magnitude of the perceptual asymmetry on the syllable identification task and that observed on a face processing task designed to involve the specialized capabilities of the right hemisphere. Strong asymmetry subjects tended to show less perceptual asymmetry favoring the left visual field on the face processing task. This can be explained if it is assumed that the strong asymmetry subjects have characteristically and asymmetrically high left hemisphere arousal which confers an advantage upon right visual field stimuli across tasks and thus counterbalances the left visual field advantage usually associated with right hemisphere specialization for face processing.

3. Objectives of the Research

The previous discussion has reviewed substantial evidence relating perceptual asymmetry and arousal asymmetry, and has hypothesized how this relationship can explain individual differences in perceptual asymmetry. There are not, however, studies available which have directly measured individual arousal asymmetry during performance of tasks associated with perceptual asymmetry. If the previously proposal is correct, there should be a correlation between the magnitude of arousal asymmetry and the magnitud^ of perceptual asymmetry.

The objectives of the present research were as follows:

a. To obtain measures of individual arousal asymmetry during performance of a task associated with a perceptual asymmetry whose magnitude varies between individuals.

b. To examine the correlation between the magnitude of the task-related arousal asymmetry and the magnitude of the perceptual asymmetry.

c. To determine the extent to which the task-related arousal asymmetry is a stable individual characteristic by examining individual arousal asymmetry over time and across varying conditions.

4. Rationale for the Experimental Approach

Electroencephalograph (EEG) Activity as a Measure of Arousal. In the present research, the level of individual hemispheric arousal asymmetry was assessed by examining the relative level of EEG activity recorded from the right and left hemisphere. Although there have been some who have argued otherwise (Kennedy, 1959), it is generally accepted that EEG activity measures the overall, ongoing activity of the brain. Classic papers describing this relationship include those by Lindsley (1952) and by Walter (1953).

A common method for describing EEG activity is in terms of the power of activity within four standard frequency bands: delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), and beta (12-50 Hz). Most experimental studies using EEG activity to assess arousal level have focused on the level of alpha activity. The level of alpha activity is inversely related to arousal level; as arousal level increases the amount of alpha activity decreases. This means that as an individual who has been relaxed and mentally uninvolved begins to perform a task, there is a decrease in the amount of alpha activity.

As Gale and Edwards (1983) point out, there is a variety of advantages associated with the use of EEG activity as a measure. It is easily observable, it varies as a function of both tonic and phasic activity, it is rapidly responsive to changes, and it can be used to discriminate between activity in different brain regions. There are numerous demonstrations of the sensitivity of EEG activity to differences between the hemispheres. For example, decrease in the relative level of left hemisphere alpha activity during verbal task performance (Galin & Ornstein, 1972) is consistent with the importance of the left hemisphere to language processing.

In terms of assessing individual differences that might be related to performance and personality, EEG activity has a number of characteristics which confirm its value. First, when assessment procedures are held constant, the level of EEG activity still differs between individuals. Although some of this difference may be due to factors such as variation in skull thickness, individual variation in cortical activity is also a significant factor. Second, although there are differences between individuals, there is evidence of considerable within-individual reliability in the level of EEG activity (Weiner & Erlichman, 1979; Dabbs & Choo, 1983). This suggests that a stable individual characteristic is being measured.

Experimental Conditions. In the present research, EEG activity was measured while the subject participated in four test conditions. The most important of the conditions was the lexical decision task. This task requires the subject to decide whether a four-letter item is a word or nonword. Each item is presented very briefly in the right or left visual field, such that the item projects initially to the left or right hemisphere, respectively. Performance of this task by right-handed individuals is generally associated with a perceptual asymmetry in the form of a right visual field advantage (Bradshaw, Gates, & Nettleton, 1977; Green, 1985). This is consistent with left hemisphere specialization for language-related processing. As the data in Table 1 indicates, there is also considerable variation between individuals in the magnitude of the perceptual asymmetry. In the present research, performance of the lexical decision task was used to assess individual perceptual asymmetry.

Subjects also participated in three other conditions: two conditions in which they were asked to close their eyes and relax (Relax 1 and Relax 2), and a condition in which they were asked to read and comprehend a short passage of text material (Read condition). These conditions were included to allow examination of the stability of individual arousal asymmetry across time within the same condition as well as across conditions. For example, one question of interest was the similarity between the arousal asymmetry observed during the Relax conditions and that observed during performance of the lexical decision task. Comparison of EEG activity during Relax 1 and Relax 2 allowed examination of the stability of individual arousal asymmetry over time.

SECTION III

RESEARCH METHOD

A. Subjects

Subjects were experimentally naive, right-handed Georgia Tech male undergraduates. Only right-handed males having right-handed parents were tested. Such a population has more homogeneous brain organization (Bryden, 1982), thus reducing data variability or the possibility of undesired confounds. Subjects were paid $20.00 or given psychology course credit in return for their participation.

The data of some of the subjects were severely contaminated by consistent EEG artifact or excessively high error rate (> 25 percent) which made interpretation of reaction time data difficult. Such contaminated data were was therefore disqualified from formal analysis. Twenty-nine individuals participated in at least one testing session. Of these, 16 subjects had uncontaminated data that were included in formal data analysis.

B. Apparatus

A diagram of the system used to control stimulus presentation and to collect data is included as Figure 2. Major components of the system include a Grass Instruments Company eight-channel EEG machine, a PDP 11/23 computer used to collect EEG data, and an IBM Personal Computer (PC) used to control stimulus presentation and to collect reaction time data.

The system includes several unique features which permit a very thorough and fine examination of the relationship between brain activity and performance. Appendix A describes factors considered in designing the system, and resultant system specifications. First, EEG activity is sampled at a very rapid rate (512 Hz), allowing a very fine analysis of the relationship between activity changes over different brain locations and over a much wider frequency range than is usually available in similar research. Recent work (Gevins, Doyle, Cutillo, Schaffer, Tannehill, Ghannan, Gilcrease, & Yeager, 1981) has suggested that analysis of the correlation between activity in different brain locations may be a fruitful, new approach to using EEG data to understand cognition and performance.

Second, the system is designed to allow storage of all raw EEG data, so that a variety of data analyses can be applied to the same set of data. Many existing procedures were designed for clinical purposes, rather than for research purposes. The availability of the raw data will allow comparison of the relative quality of different clinically-oriented procedures for experimental work. Also existing procedures can be compared with new procedures specifically designed for measurement of individual differences.

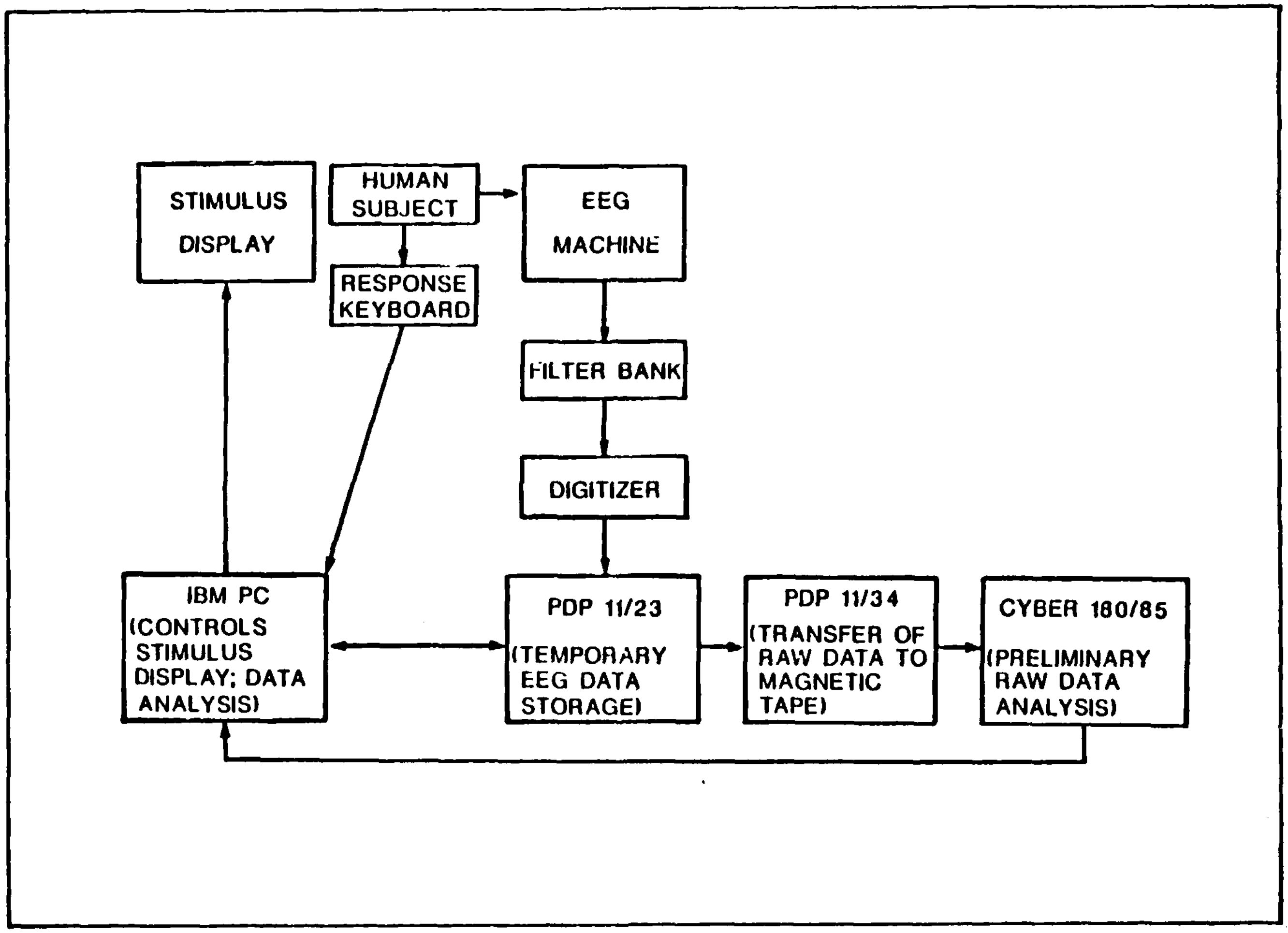

Figure 2. Diagram of the Testing and Data Analysis System.

Third, the system includes data processing filters designed at Georgia Tech to minimize signal aliasing across signal frequencies up to 50 Hz. This allows an accurate analysis of frequency across an unusually broad range, including the beta band (13-50 Hz). Although increase in the level of activity within this band is strongly related to the onset of mental activity, filtering limitations and consequent signal aliasing have often limited analysis of such activity.

The raw EEG data were initially collected on 10 megabyte hard disks in the PDP 11/23. Because of the huge quantity of data involved in research of this type, the raw EEG data could not be permanently stored or initially analyzed within the PDP 11/23. A PDP 11/34 was used to transfer the raw data from the hard disks onto magnetic tape, which is the permanent storage medium. The raw data were then transferred to the Georgia Tech CYBER 180/85, an Institute time-sharing system. Initial data analysis (the Fast Fourier Transform, see Section IV) was performed on the CYBER. Intermediate results of data analysis were then captured back to the IBM PC for further analysis.

An IBM PC with a Tecmar Graphics Board and a Quadchrome color monitor were used to present visual stimuli for the eye movement calibration, for the Reading condition, and for the lexical decision task. The PC also controlled all interval timing and, when appropriate, recorded reaction time in ms. The color monitor was set to display white stimuli on a dark gray background. The graphics-controlling software for the lexical decision task, where timing was critical, was specifically designed to minimize and control time variations due to the 16.67 ms refresh time of the color monitor's cathode ray tube.

The subject sat at a table before the display and, when appropriate, placed his head in a headrest which positioned the eyes 50.0 cm away from the center of the display. During the lexical decision task, the subject responded by using two 4.9 by 2.0 cm microswitch keys mounted on a keyboard sitting on the table. The testing room was dimly lit.

C. Stimuli

1. Read Task

The stimuli used in the Read Task were two text passages, each about 750 words in length. Each passage was presented on the visual display. Subjects press a response key to display a new page of text. A set of eight multiple choice questions concerning each passage was composed. The text passages and the question sets are included as Appendix B.

2. Lexical Decision Task

This task required the subject to decide whether a four-letter string comprised a word or nonword. The stimuli used for this task were selected from those used in previous A.R.I.-

sponsored research (Green, 1985), where they were associated with a reliable right visual field advantage.

The word items were four-letter, one-syllable nouns. Half of the words were concrete nouns and half were abstract nouns, as determined by a brief ratings study (see Green, 1985, for details). The nonwords were created by taking each word item and recombining its letters to create a one-syllable, pronounceable nonword. Homophones of real words were not used. Appendix C lists the 48 abstract words, 48 concrete words, and 96 nonwords made from each of the words, also indicating the average frequency rating.

The stimulus list was divided into three blocks of 64 trials each. Each block consisted of 16 of the concrete words, 16 of the abstract words of similar frequency, and the 32 nonwords formed from the letters of each word. Half of each item type was designated for presentation in the right visual field and half of the same type of similar frequency was designated for the left visual field. Both item type and item visual field were randomly ordered within a trial block. There was also one practice trial block of 32 items composed similarly to the test trial block.

Each letter measured 5.0 mm by 5.0 mm. The letters in each item were arrayed horizontally, with the inner edge of the most central letter (in either visual field) being 13.0 mm from the fixation point. There was 1.0 mm between the letters within each item. The letters were vertically positioned on the horizontal axis through the fixation point. Since subjects viewed from a distance 500.0 mm from the display, the four-letter item appeared between 1.49 to 4.12 degrees of visual angle.

D. Procedure for Subject Testing

1. Behavioral Assessment

The order of events for each test session is outlined in Table 2. The purpose of the behavioral assessment was to collect data on some dimensions which have been proposed as indices of brain organization (see Bryden, 1982). Such indices might be useful in interpreting individual differences in performance.

The indices used were handedness, eye dominance, tapping speed, and foot dominance. Handedness was assessed through use of a self-report measure, a modified Edinburgh Handedness Inventory (Oldfield, 1971) included as Appendix D, and through use of a performance measure, relative finger tapping speed. The handedness inventory generates handedness scores between 11 and 60, where 60 represents very strong right handedness. Relative finger tapping speed is a measure derived from neuropsychological assessment procedures for determining the locus of brain damage in the left or right hemisphere (Lezak, 1983). It is assessed by computing the difference between the hands in the average tapping rate for three, ten-second tapping trials.

TABLE 2

Events in Each Test Session.

1. Behavioral analysis
2. Attach electrodes - check for EEG artifacts
3. Eye movement calibration
4. Relax 1 condition
5. Reading condition
6. Lexical decision task
7. Relax 2 condition
8. Collection of calibration data

Footedness was assessed through the use of two procedures -- the Stamping Test (Harris, 1957) and the Kicking Test. The Stamping Test requires subjects to stamp on a small disk placed in front of them. The foot used to stamp the small disk is inferred as the dominant one. The Kicking Test requires subjects to kick a ball at a small disk mounted on a wall. The foot used to kick is inferred as dominant. By giving one point for each left foot response and two points for each right foot response (Searleman, 1980), subjects were classified as left dominant (total points = 2), mixed dominant (total points = 3), or right dominant (total points = 4).

Both foveal and peripheral acuity were assessed to insure that subjects had at least 20/40 vision at a distance of twenty feet and accurate peripheral acuity to at least five degrees, either corrected or uncorrected. Eye dominance was measured by identifying the eye used to sight a distant object through a small hole in a piece of paper.

Table 3 indicates the age, handedness score, footedness score, and eye dominance for each subject.

2. Attachment of Electrodes and Artifact Check

Using standard electrophysiological recording techniques, six gold-plated electrodes were attached to the scalp. Using the International 10-20 measurement system (Jasper, 1958), electrodes were attached in location T3 (left temporal region), C3 (left central region), P3 (left parietal region), T4 (right temporal region), C4 (right central region), and P4 (right parietal region). An electrode was attached to the outer canthus of each eye to allow recording of horizontal eye movements. Electrodes were attached to each ear lobe to provide a linked ear reference. An electrode was attached to the chest to monitor cardiac activity that might produce artifacts in the EEG data.

After the electrodes were attached, initial EEG data were measured to validate that the electrodes had been attached properly, and to allow initial review for artifact that might contaminate the data. Of particular interest was artifact due to cardiac activity and chronic muscle tension. If such artifacts were present, electrode position was adjusted and/or the subject was encouraged to try to reduce muscle tension, particularly in the jaw, forehead, or at the back of the neck.

3. Eye Movement Calibration

Eye movement calibration was done to allow assessment of when inappropriate eye movement had occurred during the lexical decision task. The subject placed the head in the headrest and was asked to visually track a small plus that appeared on the visual display. Every two seconds, the plus moved from a central location to a position corresponding to the inner edge of the location of the stimuli used in the lexical decision task. EEG data were recorded while the subject visually tracked the plus

TABLE 3

Subject Characteristics.

Subject	Age	Handedness Score	Tapping Score Left	Tapping Score Right	Footedness Score	Eye Dominance
1	18	54	55.0	57.0	4	R
2	19	45	50.3	60.0	4	R
3	19	53	47.7	50.3	4	L
4	18	49	46.3	53.0	3	R
5	18	45	46.3	54.3	4	L
6	19	50	59.7	69.3	4	R
7	18	46	45.3	43.7	3	R
8	23	54	50.7	56.7	4	R
9	22	55	63.0	65.0	4	L
10	21	54	52.3	54.0	4	L
11	18	56	58.0	62.0	4	L
12	18	47	52.0	61.0	4	R
13	18	54	48.0	50.7	4	L
14	18	50	44.0	49.3	4	R
15	18	45	64.3	69.3	4	R
16	18	53	43.3	51.0	4	L
Mean =	18.94	50.63	51.64	56.66		
S.D. =	1.61	3.98	6.65	7.32		

for a period lasting about one minute. The filter on the EEG channel being used to monitor eye movement was adjusted such that such movement could be detected from the EEG write-out for that channel.

4. Relax 1 Condition

Each subject was instructed to place his head in the headrest, to close his eyes, and to relax. He was asked to keep tongue, eye, and body movement at a minimum. This condition lasted four minutes.

5. Read Condition

The subject was asked to place his head in the headrest and to read the text presented on the visual display before him. He was allowed to move his eyes naturally in order to read. The reading lasted for four minutes. To validate that reading and comprehension had occurred, the subject was asked to respond to a set of eight questions about the text material. The text materials and questions are included as Appendix B. Subject responses to the questions are included as Appendix E.

6. Lexical Decision Task

It was originally intended that responding hand (left or right) and response assignment (index or middle finger keypress for "word" stimuli) should be equally represented within the subject sample. However, technical difficulties made this impossible. The hand and response assignment used by subjects included in data analysis are shown in Table 4.

Within each test session, each subject was presented with one practice block (32 trials) and three test blocks (64 trials each). Each test trial proceeded as follows. A small fixation plus appeared in the center of the screen. The subject was instructed to carefully fixate on the plus, and when fixated to press both response keys to initiate the trial. The fixation plus remained on, but 500 ms later a stimulus item appeared for 150 ms in the left or right visual field. The stimulus was immediately followed by a 150 ms mask. The mask consisted of four square patches, one overlaying each of the areas in which a stimulus letter had appeared. Each patch looked like a very dense array of fine, bright dots and was created by lighting all of the CRT pixels in the area over each letter. The fixation plus disappeared with the offset of the mask. The subject's task was to judge whether each item was a word or a nonword, and to indicate the decision with an appropriate keypress. Following response, performance feedback (either the correct reaction time or the word "ERROR") appeared for one second in the center of the screen above the former location of the plus. The plus then reappeared signalling the beginning of a new trial.

After each test block subjects were encouraged to lower their error rate if it had exceeded 25 percent for that block.

TABLE 4

Subject Responding Hand and Response Assignment.
Response Assignment (RA) 1: Word = index finger keypress,
Nonword = middle finger keypress.
RA2: reverse of RA1.

Response Assignment -->	1	2
Responding Hand		
Left	_Ss_ 1, 2, 3, 4, 5	_Ss_ 9, 10, 11, 12, 13
Right	_Ss_ 6, 7, 8	_Ss_ 14, 15, 16

They were also asked to reduce eye or body movement if observation of the EEG write-out indicated that these were occurring at inappropriate times (e.g., during stimulus presentation) or were causing artifacts in the EEG data. Subjects having average error rates exceeding twenty percent were not asked to return for the second session.

7. Relax 2 Condition

This was identical to the Relax 1 Condition, except that it occurred after the subject had performed the lexical decision task.

8. Collection of Calibration Data

Calibration data were collected for use in determining whether there were differences in gain between the EEG channels, and to allow adjustment for any differences.

E. Procedure for EEG Data Collection

EEG activity was monitored throughout the testing by observation of the paper write-out from the EEG machine. It was impractical to continuously collect and store EEG data throughout each session because the required data storage requirements would be enormous. A subset of the data was therefore collected and stored for subsequent analysis.

During performance of the lexical decision task, EEG data collection for each trial was initiated by the keypress indicating visual fixation at the beginning of the trial and was terminated by the keypress response indicating the subject's word-nonword decision. During the Read and Relax conditions, EEG data were collected and stored for alternate four second intervals.

SECTION IV

RESULTS AND DISCUSSION

A. Introduction

Application of the method described in Section III has produced a large and rich data base useful for examining the relationship between cerebral activity and performance. Because of the nature of the data collection system, the EEG data base is unusual in allowing very fine analysis of cerebral activity across a broad range of frequencies.

The results reported here represent a subset of the possible data analyses that can be applied. The selected analyses represent a fairly conventional approach to addressing the questions of major interest. It is hoped that future work will include additional analysis that can take further advantage of the data to understand the relationship between cerebral activity and performance.

B. Approach to Analysis of EEG Data

1. Review of Data

In using EEG data to understand human cognition and performance, an important first step in data analysis involves review of the data to eliminate contaminated data samples. The goal is to include in data analysis samples which are primarily a function of the cerebral activity of interest, e.g., that associated with lexical decision-making, and to exclude samples which are predominated by less interesting activity, e.g., irrelevant muscle movement.

For each of the Relax and Read conditions, a total of thirty samples of EEG data, each four seconds in length, was collected during each test session. The paper write-outs were visually reviewed by the neurologist on the research team to eliminate data samples which had been contaminated by artifact. Typical factors causing artifact were large eye movements, motor movement, or temporary detachment of electrodes.

For the lexical decision task, a total of 192 samples of EEG data was collected during each session. The length of the sample varied as a function of the subject reaction time. These samples were also reviewed for artifact. In addition, the write-out from the EEG machine channel recording eye movement was used to eliminate samples during which an inappropriate eye movement had occurred. An inappropriate eye movement was identified as one that had occurred within the first 600 ms of the data sample, i.e., between the initiation of the "ready" keypress and the offset of the stimulus. Samples for which the subject response had been incorrect were also eliminated.

Table 5 indicates the number of samples analyzed for each subject for each condition.

2. Assessment of Power Within the Alpha Band

A Fast Fourier Transform (Rader, 1979) was used to compute the spectral distribution for valid data. The spectral distribution describes power as a function of frequency, and was used to infer the power within the alpha band. It is important to note that because gains in the measurement system were not assessed, power is in terms of relative (rather than absolute) watts. The relative level of power is a reflection of the level of alpha activity. For purposes of simplicity, the level of power within the alpha band will be referred to as "alpha" in all subsequent discussion.

One important decision in applying the FFT involved choosing the time interval for analysis, or the "window size." Window size is directly related to the frequency resolution of the spectral distribution obtained from the FFT -- as window size increases, the frequency resolution increases. However, using very large windows has a negative impact because this reduces the number of estimates of power obtained from the data. Smaller windows generally provide more estimates. Window sizes of one-half to two seconds long are generally used.

For the Read and Relax conditions, it was decided to apply two, non-overlapping two-second windows to each four second sample. This provided two estimates of the spectral distribution for each four second sample, with a one-half Hz frequency resolution for frequencies between one and fifty Hz. The power for frequencies between eight and twelve Hz was summed to obtain an estimate of the power within the alpha band.

For the lexical decision task, application of the FFT was complicated by the fact that sample lengths varied as a function of reaction time. The validity of the FFT for estimating spectral parameters depends on having constant sample sizes. In addition, many of the samples were relatively short (less than 750 ms), thus reducing the frequency resolution.

It was decided to analyze constant-size intervals that would be available from each data sample, regardless of reaction time. The FFT was applied to the 250 ms interval just before stimulus onset (pre-stimulus interval) and to the 250 ms interval immediately after stimulus onset (post-stimulus interval). The pre-stimulus interval represents a period when the subject should be aroused to process the stimulus. The post-stimulus interval represents a period when the subject is actively processing the stimulus.

TABLE 5

Number of Valid EEG Data Samples
for Each Subject.

Condition Subject	Relax 1	Read	Lexical Decision Task	Relax 2
1	2	9	128	21
2	9	12	113	6
3	12	8	75	8
4	12	12	126	20
5	16	10	134	18
6	11	12	83	9
7	15	14	111	21
8	14	18	61	6
9	9	*	62	20
10	7	9	88	16
11	9	6	86	11
12	14	8	84	*
13	26	18	88	23
14	9	11	102	13
15	13	8	119	17
16	10	11	130	10

*Data unavailable due to hardware failure.

Analysis of 250 ms intervals results in a four Hz frequency resolution. It was therefore possible to infer the power within the alpha band (8-12 Hz). It was not possible to infer the power associated with specific frequencies within that range, e.g. the power from 9-10 Hz. This was not problematic, however, since the major interest was in overall power within the alpha band.

C. Overall Analysis of Perceptual Asymmetry

This analysis focused on the reaction time data collected during performance of the lexical decision task. Each subject's data were scrutinized for possible speed-accuracy tradeoff. This was done by comparing the median left and right visual field reaction time for each subject, and determining whether the performance advantage inferred from this was consistent with that implied by comparison of the average percentage of error for the left and right visual field. If the percentage of error differed by ten percent within the visual fields and suggested that performance was better in the visual field associated with the slower median reaction time, then occurrence of a speed-accuracy tradeoff was inferred. None of the subjects were eliminated for this reason.

For each subject, the median reaction time was computed for each stimulus type (concrete word, abstract word, nonword) by visual field (left,right) condition, collapsing over the three test blocks. In computing the median, only trials for which there were valid EEG data were included. That is, reaction times for trials associated with EEG artifact or eye movement were excluded. The corresponding average percentage of error was also calculated.

Individual subject data are contained in Table 6. The difference between overall median left and right visual field reaction time represents the perceptual asymmetry of each subject. Analysis of variance (ANOVA) was done on the median reaction times using stimulus type and visual field as within-subjects variables. There were main effects of visual field ($F(1,15)=33.24$, $p<0.001$) and of stimulus type ($F(2,30)=22.27$, $p<0.001$), but no interaction. Reaction time to stimuli in the right visual field (758 ms) was faster than that to stimuli in the left visual field (811 ms). This perceptual asymmetry favoring the right visual field is consistent with the idea of left hemisphere specialization for language-related tasks. Reaction time was similar for abstract words (736 ms) and concrete words (737 ms), but slower for nonwords (836 ms). This is similar to results obtained in previous research (Green, 1985).

Analysis of variance was done on an arcsine transformation of percentage of error using the same design as that for the reaction time data. There was significantly less error for the right visual field (11.5 %) than for the left visual field (17.8 %, $F(1,15)=20.75$, $p<0.001$). There was significantly less error for abstract words (13.2 %) or for concrete words (10.8 %) than for nonwords (17.3 %, $F(2,30)=7.6$, $p<0.01$).

TABLE 6

Lexical Decision Task: Median Reaction Time and Percentage of Error.

Reaction Time :

Stimulus Type -->	Abstract Word		Concrete Word		Nonword		Overall		
Visual Field -->	L	R	L	R	L	R	L	R	PA* (L - R)
Subject									
1	725	825	796	777	947	802	841	802	39
2	504	500	505	502	604	547	562	533	29
3	804	764	778	843	764	651	779	758	21
4	753	708	762	707	807	760	782	743	39
5	759	641	679	679	845	759	772	705	67
6	552	535	584	563	629	610	569	559	10
7	775	703	729	671	825	721	777	718	59
8	1346	1094	1279	1209	1273	1263	1283	1205	78
9	733	729	748	754	967	827	827	798	29
10	632	604	749	586	825	736	739	698	41
11	813	776	874	734	1036	1000	926	829	97
12	603	534	600	505	654	591	624	581	43
13	736	705	745	701	883	875	809	775	34
14	768	748	759	753	795	821	791	779	12
15	889	813	935	746	1171	984	1001	866	97
16	741	737	666	681	969	818	886	775	111
Mean	758	714	762	713	875	798	811	758	50
S.D.	185.8	142.1	173.8	163.8	183.8	177.9	172.2	152.9	31.3

Percentage of error:

Stimulus Type -->	Abstract Word		Concrete Word		Nonword		Overall	
Visual Field -->	L	R	L	R	L	R	L	R
Subject								
1	29.17	4.17	12.50	4.17	18.75	8.33	19.79	6.25
2	8.33	16.67	4.17	4.17	10.42	8.33	8.33	9.38
3	20.83	12.50	16.67	4.17	6.25	8.33	12.50	8.33
4	4.17	0.00	8.33	8.33	25.00	10.42	15.62	7.29
5	12.50	8.33	8.33	4.17	12.50	10.42	11.46	8.33
6	25.00	8.33	20.83	0.00	27.08	22.92	25.00	13.54
7	25.00	20.83	41.67	8.33	31.25	18.75	32.29	16.67
8	4.17	12.50	12.50	12.50	14.58	16.67	11.46	14.58
9	20.83	8.33	20.83	8.33	16.67	16.67	18.75	12.50
10	16.67	8.33	12.50	16.67	35.42	29.17	25.00	20.83
11	8.33	4.17	25.00	4.17	14.58	10.42	15.62	7.29
12	16.67	8.33	12.50	12.50	12.50	14.58	13.54	12.50
13	4.17	4.17	4.17	0.00	16.67	12.50	10.42	7.29
14	37.50	12.50	20.83	4.17	29.17	29.17	29.17	18.75
15	29.17	12.50	20.83	0.00	20.83	16.67	22.92	11.46
16	8.33	8.33	8.33	4.17	16.67	10.42	12.50	8.33
Mean	16.93	9.37	15.62	5.99	19.27	15.24	17.77	11.46
S.D.	10.37	5.16	9.44	4.80	8.18	6.88	7.22	4.45

* Perceptual Asymmetry

The results of these analyses are consistent with the idea that the left hemisphere is specialized for language-related processing and with experimental studies demonstrating an overall perceptual asymmetry in the form of the right visual field advantage when right-handed individuals perform a lexical decision task. The magnitude of the overall perceptual asymmetry (about 50 ms) is similar to that observed previously (see Table 1; also Green, 1985).

As in the previous research, there is also considerable between-individual variation in the magnitude of the asymmetry. Although all subjects exhibited a perceptual asymmetry favoring the right visual field, there is considerable variation in the magnitude of this asymmetry, with some individuals showing a large asymmetry (e.g., Subjects 11,15,16), some showing a moderate asymmetry (e.g., Subjects 5,7), and some showing only a small asymmetry (Subjects 10,12). Such variation is what Levy, et al. (1983) have associated with individual differences in arousal asymmetry. In the present study, the magnitude of between-individual variation is somewhat smaller than that observed in the previous work, where some individuals even had perceptual asymmetries favoring the left visual field (see Table 1). In the present study, perhaps the elimination of data associated with eye movement or EEG artifact decreased the error variance in the data.

D. Overall Analysis of Arousal Asymmetry During Lexical Decision Task

This analysis focused on the EEG data collected during performance of the lexical decision task. For each subject, the median alpha was computed for each recording time (pre- or post-stimulus), by recording location (temporal, central, parietal) by hemisphere (right, left) condition, collapsing over the three test blocks. Individual arousal asymmetry was calculated for each recording location by subtracting the median left hemisphere alpha from the median right hemisphere alpha. Since arousal level is inversely related to alpha level, positive values suggest the left hemisphere is more aroused.

Individual subject data are shown in Table 7. An ANOVA was done using recording time, recording location, and hemisphere as within-subjects factors. There was a significant main effect of hemisphere ($F(1,15)=7.95$, $p<0.05$). There was significantly less left hemisphere alpha (12.20) than right hemisphere alpha (15.7), consistent with increased arousal of the language-specialized left hemisphere during lexical decision-making. There was also a main effect of recording location ($F(2,30)=12.44$, $p<0.001$). Alpha decreased from the parietal (19.73) to central location (13.58), and was least at the temporal location (8.56).

Although the overall analysis indicated that the left hemisphere was more aroused than the right hemisphere, there was considerable individual variation in the magnitude and nature of arousal asymmetry. The next analysis examines whether this

TABLE 7

Lexical Decision Task: Median Alpha (watts).

<u>Pre-stimulus interval</u>:

Hemisphere->	Left			Right			Arousal Asymm. (Right - Left)		
Location->	Temp	Cent	Par	Temp	Cent	Par	Temp	Cent	Par
Subject									
1	5.95	7.90	9.00	5.00	6.50	7.25	-0.95	-1.40	-1.75
2	8.90	13.80	13.10	7.50	12.90	14.90	-1.40	-0.90	1.80
3	16.10	11.10	14.10	12.30	20.30	20.80	-3.80	9.20	6.70
4	6.50	10.70	10.90	6.20	8.85	10.85	-0.30	-1.85	-0.05
5	4.05	7.60	9.20	5.30	8.15	10.15	1.25	0.55	0.95
6	3.40	7.70	8.10	5.10	9.50	18.80	1.70	1.80	10.70
7	5.00	8.60	13.70	7.90	12.00	16.70	2.90	3.40	3.00
8	5.10	5.90	6.95	6.25	7.95	8.40	1.15	2.05	1.45
9	5.90	7.10	6.10	6.65	6.35	6.80	0.75	-0.75	0.70
10	13.55	8.45	10.40	7.65	10.50	7.90	-5.90	2.05	-2.50
11	3.55	8.95	12.05	7.30	15.10	18.20	3.75	6.15	6.15
12	14.25	30.15	54.05	28.15	46.25	84.05	13.90	16.10	30.00
13	9.25	24.60	32.20	10.00	22.40	43.10	0.75	-2.20	10.90
14	7.80	18.70	20.55	9.40	18.70	41.45	1.60	0.00	20.90
15	14.10	19.70	32.30	20.70	31.20	49.40	6.60	11.50	17.10
16	7.15	11.50	16.85	8.15	14.45	16.65	1.00	2.95	-0.20

<u>Post-stimulus interval</u>:

1	5.50	7.95	8.50	5.45	7.75	7.80	-0.05	-0.20	-0.70
2	6.60	10.60	13.20	9.30	14.90	15.90	2.70	4.30	2.70
3	13.80	11.70	18.30	15.00	21.30	25.40	1.20	9.60	7.10
4	7.85	9.50	9.85	6.65	8.70	14.30	-1.20	-0.80	4.45
5	3.50	11.95	13.00	4.35	11.10	13.45	0.85	-0.85	0.45
6	5.20	7.10	7.80	5.70	8.00	12.10	0.50	0.90	4.30
7	4.30	7.60	11.80	8.20	8.70	14.30	3.90	1.10	2.50
8	5.70	5.45	7.55	7.00	8.65	7.20	1.30	3.20	-0.35
9	5.10	11.50	8.05	8.20	10.75	13.70	3.10	-0.75	5.65
10	14.05	7.85	10.95	6.60	9.10	12.85	-7.45	1.25	1.90
11	3.75	10.70	12.70	5.45	11.55	15.40	1.70	0.85	2.70
12	12.35	19.35	39.50	23.35	33.30	69.00	11.00	13.95	29.50
13	6.15	22.05	49.35	11.60	29.85	64.00	5.45	7.80	14.65
14	6.35	13.15	14.50	6.25	10.30	20.10	-0.10	-2.85	5.60
15	10.60	16.00	20.90	15.00	20.50	32.20	4.40	4.50	11.30
16	8.85	13.30	17.20	6.10	15.55	17.25	-2.75	2.25	0.05

variation is related to the variation in perceptual asymmetry described earlier.

E. Analysis of the Relationship Between Perceptual Asymmetry and Arousal Asymmetry During the Lexical Decision Task

This analysis involved examination of scatter plots illustrating the relationship between perceptual and arousal asymmetry, followed by computation of the Pearson product-moment correlation coefficient to better quantify the nature of observed relationship. In several cases, the scatter plots were used to identify substantially deviant, outlying data points. The correlations including versus excluding such points were then compared.

In Figures 3 through 8 are scatter plots illustrating the relationship between individual perceptual and arousal asymmetry for each recording location and time. In these and subsequent figures, the best-fitting regression line is shown where the relationship was significant. The strongest relationship is found for arousal asymmetry measured at either the temporal or central location during the pre-stimulus interval (see Figures 3 and 4). For either location, the data of Subject 12 are substantially deviant from the rest because of his very large arousal asymmetry.

In Table 8 are included the correlations between perceptual asymmetry and arousal asymmetry for each recording location and recording time. Although some of the correlations are substantial, none is significant when all of the data are included. However, exclusion of the data of Subject 12 causes several of the correlations to become significant. There is a significant correlation between perceptual asymmetry and arousal asymmetry measured at the temporal location for the pre-stimulus period ($r(14)=0.498$, $p<0.05$). There is also a correlation closely approaching significance for the central location for the same recording period ($r(14)=0.453$, $p<0.10$). When the arousal asymmetries for the temporal and central locations are averaged, the correlation with perceptual asymmetry is more highly significant ($r(14)=0.58$, $p<0.02$).

The results suggest that there is a relationship between perceptual asymmetry and arousal asymmetry when arousal asymmetry is measured at certain recording locations during certain aspects of performance. The fact that arousal asymmetry just prior to (rather than immediately following) stimulus onset is related to perceptual asymmetry points to the importance of asymmetry in cognitive activities which occur prior to stimulus onset, rather than those more closely associated with the stimulus processing itself. Such pre-stimulus activities include attentional activities which prepare the human information processing system for, and which facilitate, stimulus processing. The present data would thus support the view that differences between the hemispheres in attentional activity, resulting in attentional biases

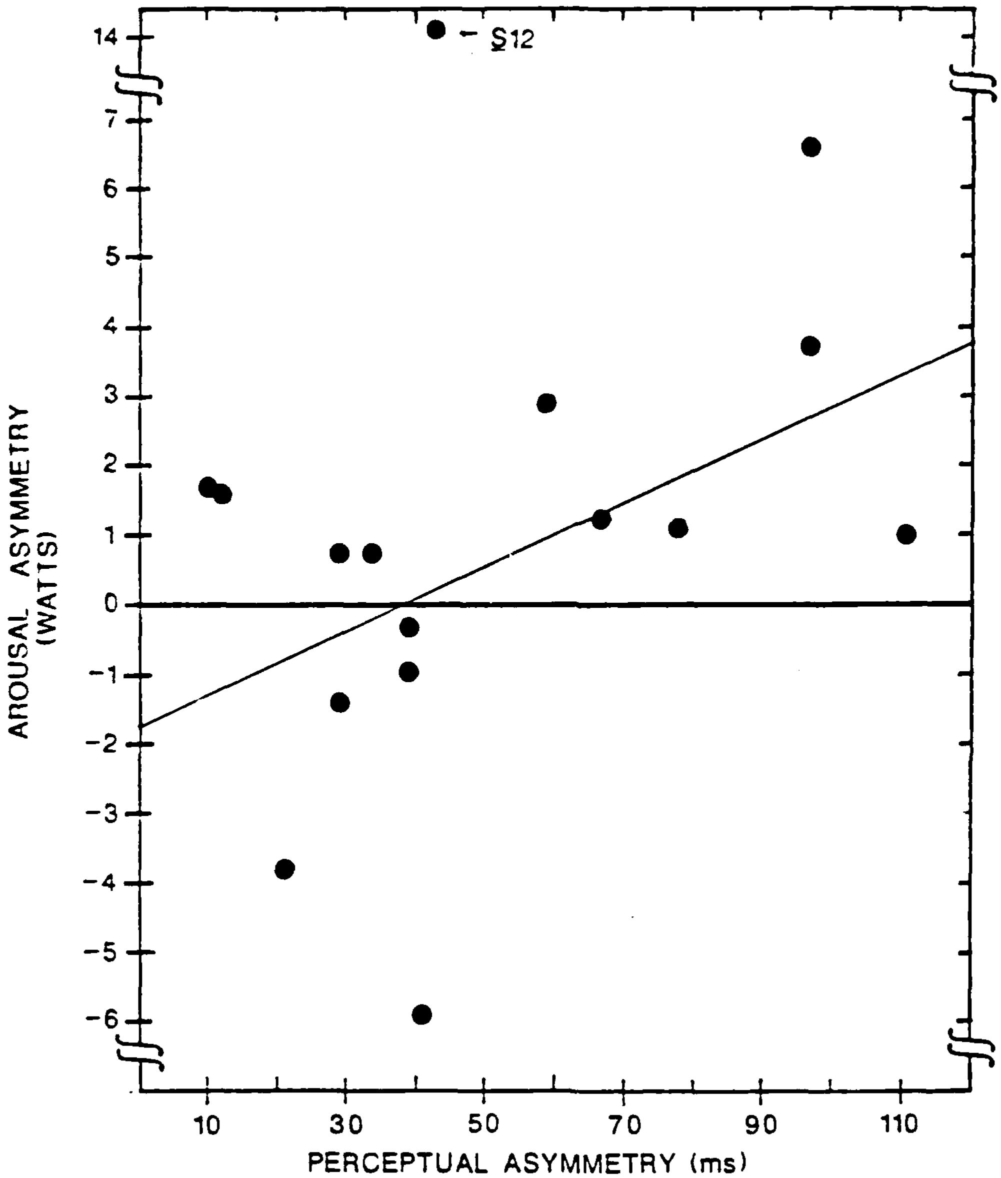

Figure 3. The Relationship Between Perceptual Asymmetry and Pre-stimulus Arousal Asymmetry at the Temporal Locations During the Lexical Decision Task.

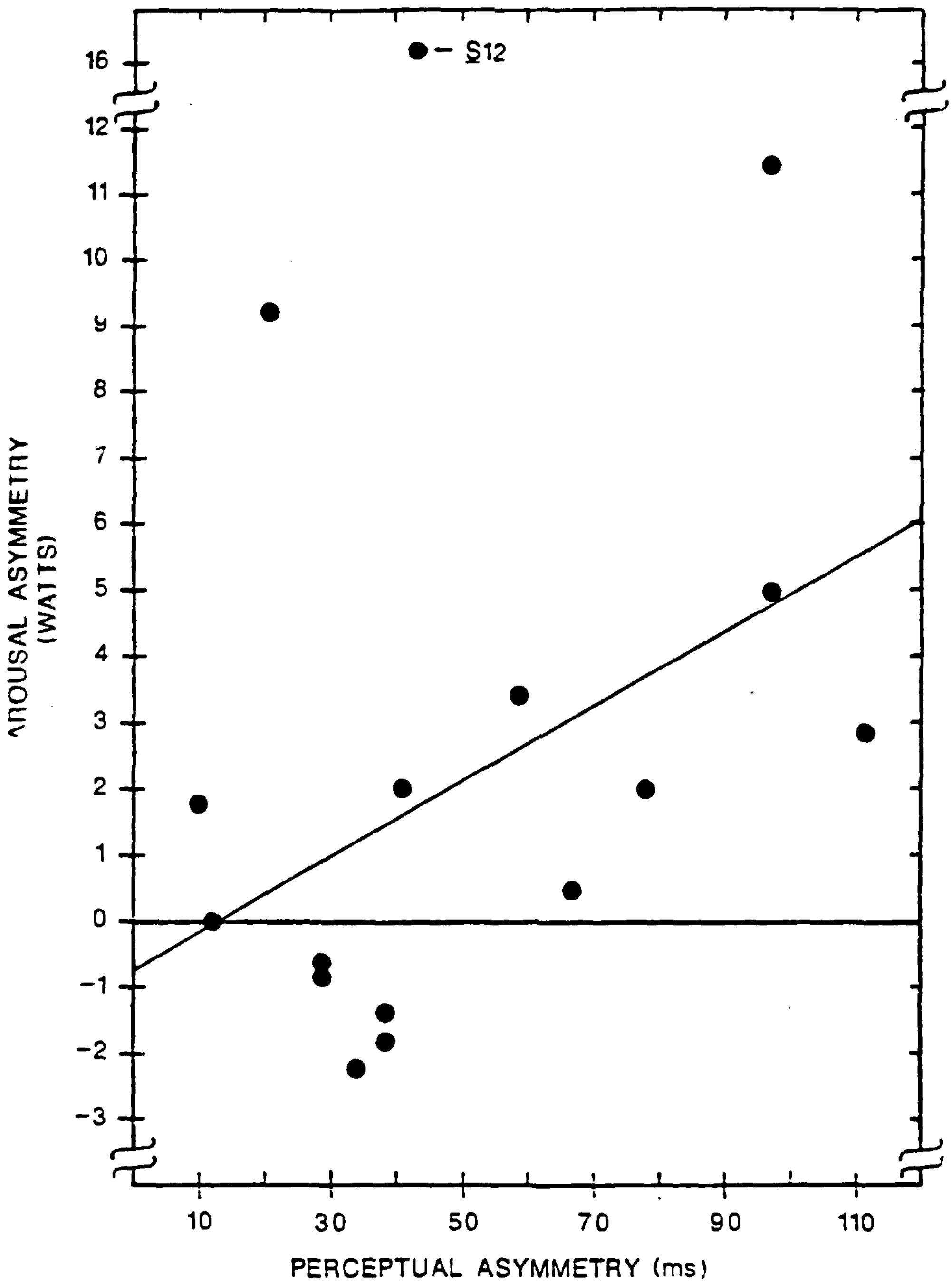

Figure 4. The Relationship Between Perceptual Asymmetry and Pre-stimulus Arousal Asymmetry at the Central Locations During the Lexical Decision Task.

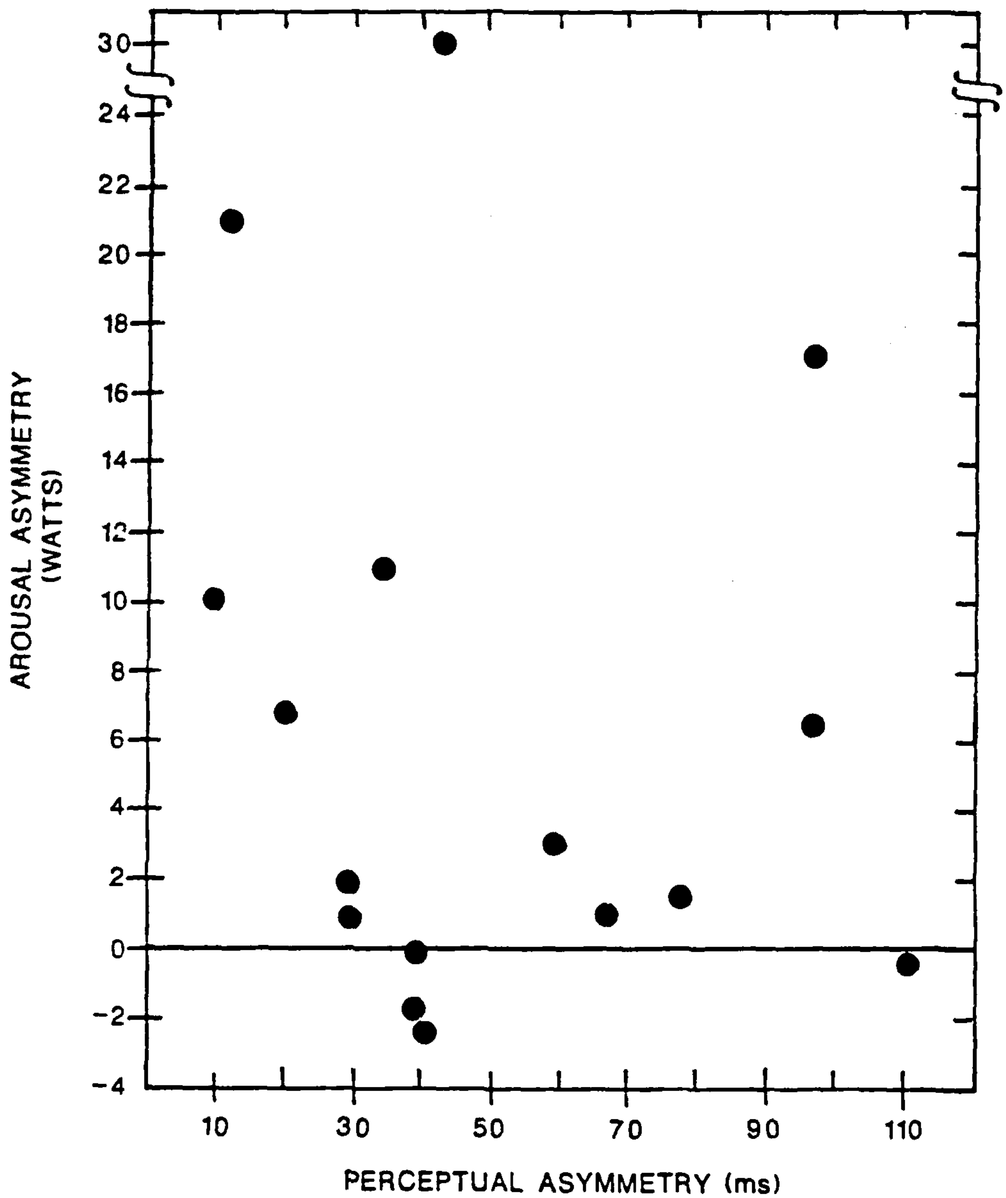

Figure 5. The Relationship Between Perceptual Asymmetry and Pre-stimulus Arousal Asymmetry at the Parietal Locations During the Lexical Decision Task.

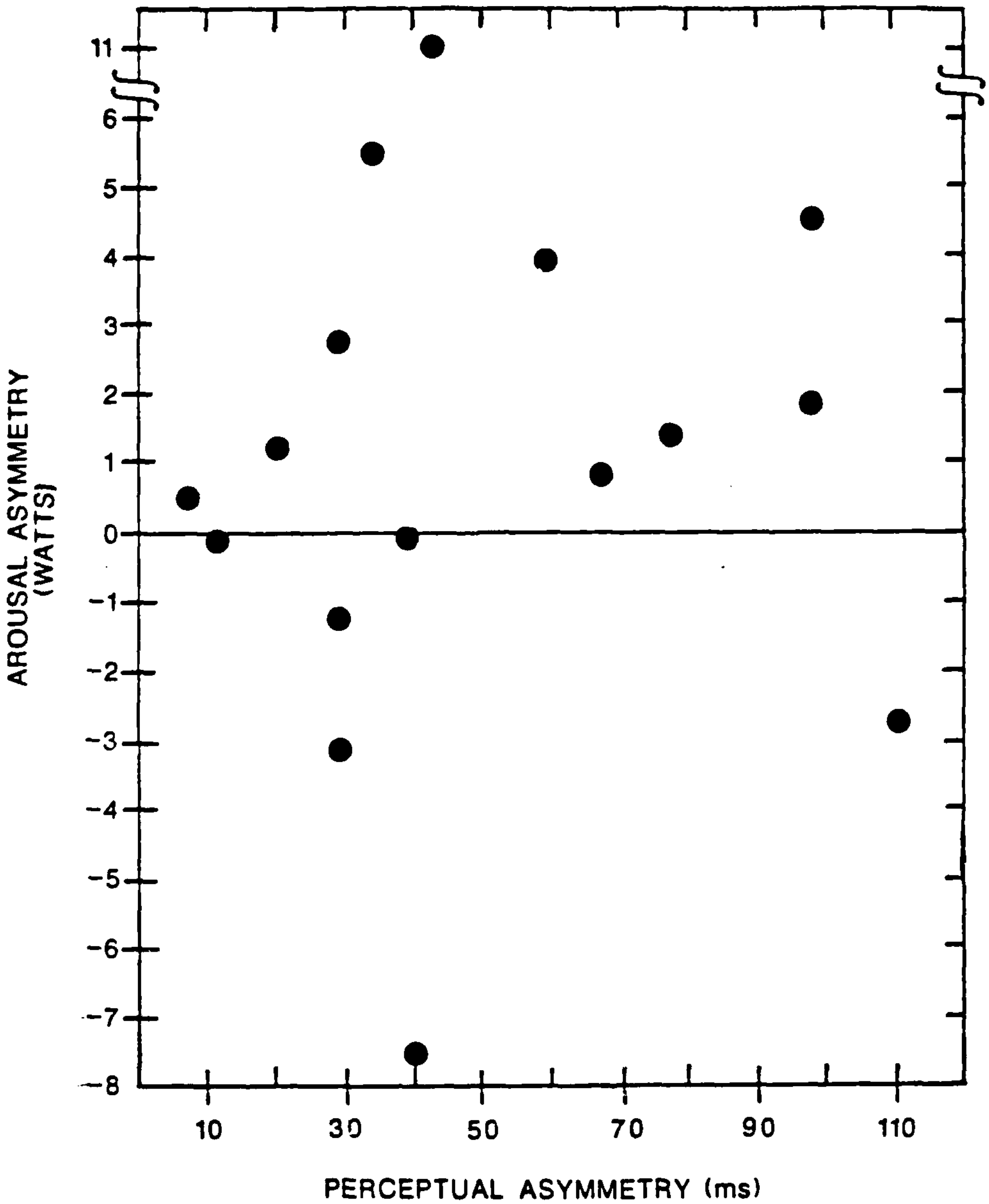

Figure 6. The Relationship Between Perceptual Asymmetry and Post-stimulus Arousal Asymmetry at the Temporal Locations During the Lexical Decision Task.

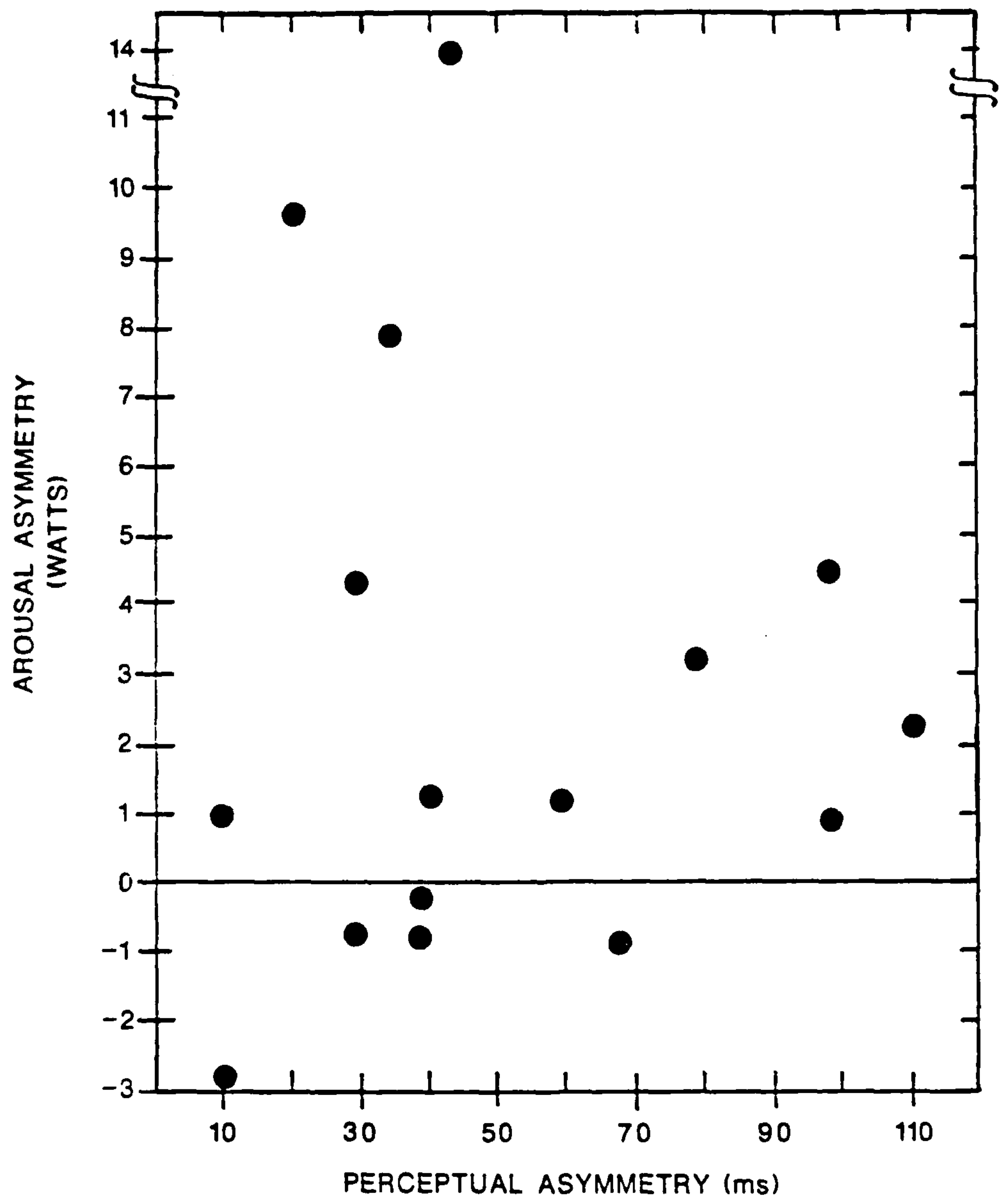

Figure 7. The Relationship Between Perceptual Asymmetry and Post-stimulus Arousal Asymmetry at the Central Locations During the Lexical Decision Task.

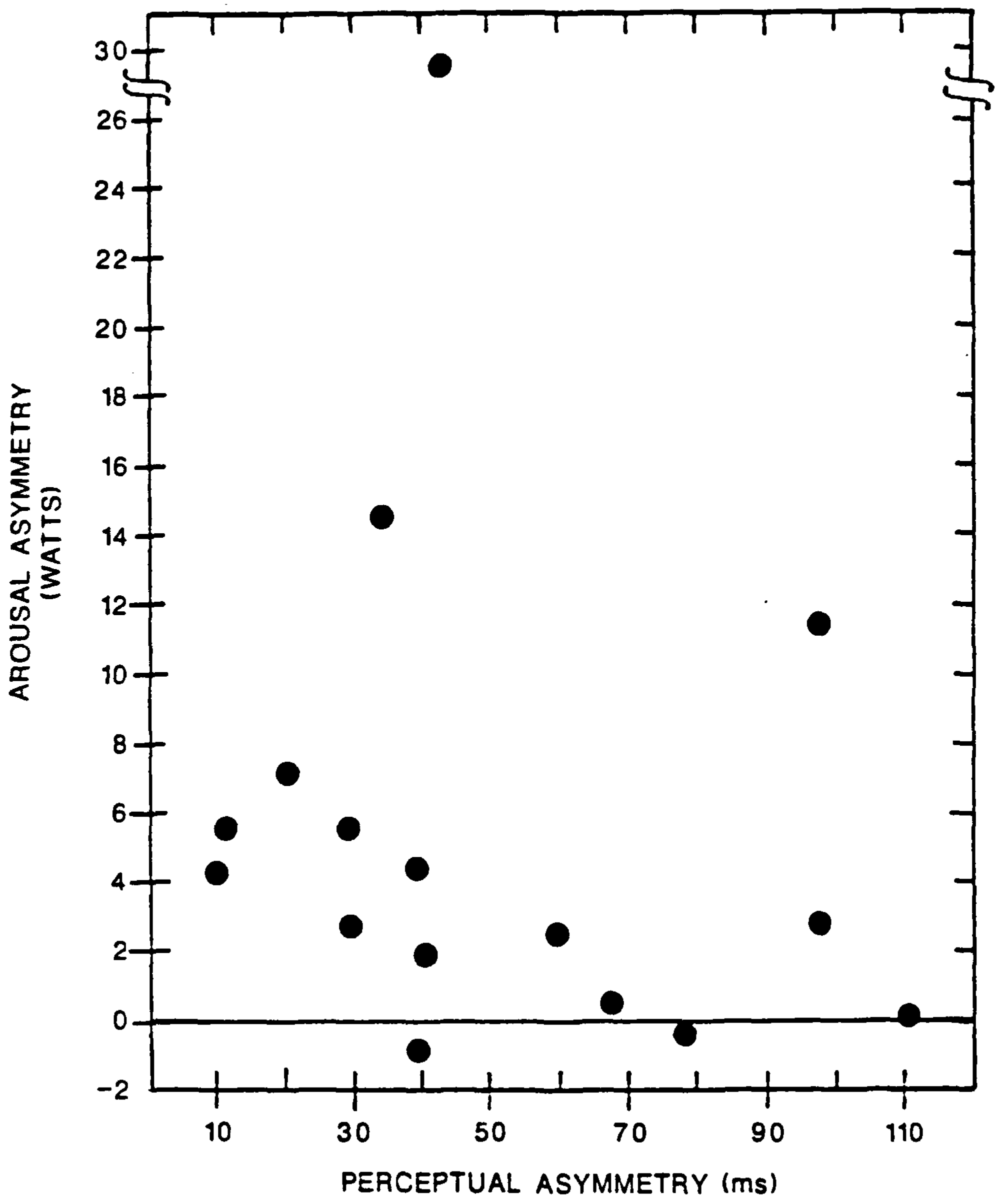

Figure 8. The Relationship Between Perceptual Asymmetry and Post-stimulus Arousal Asymmetry at the Parietal Locations During the Lexical Decision Task.

TABLE 8

Lexical Decision Task: Correlation Between Perceptual Asymmetry and Arousal Asymmetry.

Measure of Arousal Asymmetry	Correlation All Ss	Excluding Outlier (S-)	
Pre-stimulus			
Temporal Location	0.277	0.498*	(S12)
Central Location	0.295	0.453?	(S12)
Parietal Location	-0.159	--	
Post-stimulus			
Temporal Location	-0.033	--	
Central Location	-0.022	--	
Parietal Location	-0.174	--	

? $p < 0.10$
* $p < 0.05$

(Kinsbourne, 1973), play a role in determining perceptual asymmetry.

The data also have some implications for the relative importance of left hemisphere language specialization versus arousal asymmetry (and thus, perhaps, attentional biases) in determining overall perceptual asymmetry. The results suggest arousal asymmetry alone is not sufficient for explaining perceptual asymmetry. If arousal asymmetry were sufficient, one would expect individuals having higher right hemisphere arousal also to have perceptual asymmetry favoring the left visual field. In fact, although individuals with higher right hemisphere arousal also tended to have smaller perceptual asymmetries, none exhibited a left visual field advantage. This would also suggest that while arousal asymmetry interacts with left hemisphere language specialization in determining overall perceptual asymmetry, hemispheric specialization has a larger impact than arousal asymmetry in determining overall perceptual asymmetry.

The finding that arousal asymmetry measured at the temporal location was most closely related to perceptual asymmetry is consistent with evidence indicating the importance of the temporal lobes to memory retrieval processes (Kolb & Wishaw, 1980), such as occur during lexical decision-making. Clinical neuropsychological evidence indicates that damage to the left temporal region, particularly the hippocampus, is related to languge deficits, including difficulty with word recognition.

The advantage of the temporal location may also be related to its proximity to the location of the reference electrodes. Because a linked ear reference system was used, the temporal electrodes were closest to (and the parietal electrodes were the farthest from) the reference electrodes. The noise sources for the temporal electrodes were therefore likely to be most similar to those for the reference electrodes. Since the level of alpha activity for a given location is determined in relationship to the level of the reference, and the noise levels were likely to be most similar between the temporal and reference locations, the temporal locations are likely to provide very pure measures of non-noise activity of interest, in this case, alpha activity.

In the present sample of subjects, Subject 12 provided data consistently aberrant to the relationship described above. For the temporal location, pre-stimulus interval, Subject 12 had the largest alpha asymmetry , yet had only a moderate perceptual asymmetry. Compared with most other subjects, Subject 12 also had a substantially higher level of alpha activity, especially for the right hemisphere. Although factors related to electrode placement or skull thickness may be related to high alpha level, this might also indicate that this subject did not become as highly aroused by the task as did the other subjects. If this is the case, then this suggests that arousal asymmetry may not be predictive of perceptual asymmetry when overall arousal level is low.

F. Overall Analysis of Arousal Asymmetry During the Relax and Read Conditions

The primary purpose for including these conditions was for use in examining the reliability of individual arousal asymmetry across conditions. However, since the data were available, overall ANOVAs were also performed. For each subject for Relax 1, Relax 2, and Read, the median alpha was computed for each recording location (temporal, central, parietal) and for each hemisphere. Arousal asymmetries were computed as they had been done for the lexical decision task. These data are included in Tables 9 and 10.

A within-subjects ANOVA was done on the Relax data using hemisphere, recording location, and time (Relax 1 or 2) as factors. The only main effect was recording location ($F(2,30)=16.12$, $p<0.001$). As in the lexical decision task, alpha decreased from the parietal (111.26) to central (58.23) to temporal location (20.00).

An ANOVA of the Read data also indicated only a main effect of recording location. Alpha decreased from the parietal (34.89) to central (23.50) to temporal location (10.78).

The absence of overall hemispheric differences is somewhat surprising, especially for the Read task which is generally associated with less alpha for the left hemisphere. The absence of less left hemisphere alpha for the Read task may be related to the limited number of good data samples obtained for this condition (see Table 5). Of the thirty data samples obtained for each subject, for the great majority of subjects considerably fewer than fifty percent of these samples did not contain artifacts. Because reading involves eye movements, many of the EEG data samples were excluded due to eye movement artifact. If there was eye movement artifact any time during the four-second sample, the entire sample was eliminated. Perhaps use of a shorter data sample might increase the proportion of usable samples. It is notable that for the lexical decision task, which used data samples generally less than one second, a greater proportion of the data samples were nonartifactual, and significantly less left hemisphere alpha was observed.

G. Analysis of the Reliability of Individual Arousal Asymmetry

The purpose of this analysis was to examine the extent to which individual arousal asymmetry during the lexical decision task was characteristic of the individual across conditions. This was done by examining the correlations between lexical decision task arousal asymmetry and that measured during the Relax and Read conditions. The relationships between arousal asymmetries during the Relax and Read conditions and between Relax 1 and Relax 2 were also examined.

As can be seen in Table 11, there are several significant correlations. The arousal asymmetries which correlated with

TABLE 9

Relax Conditions: Median Alpha (watts).

<u>Relax 1</u>:

Hemisphere->	Left			Right			Arousal Asymm. (Right - Left)		
Location->	Temp	Cent	Par	Temp	Cent	Par	Temp	Cent	Par
Subject									
1	16.05	56.55	138.55	12.20	35.55	52.10	-3.85	-21.00	-86.45
2	18.35	74.25	135.80	18.15	63.75	210.05	-0.20	-10.50	74.25
3	25.95	64.15	76.25	25.30	68.20	73.05	-0.65	4.05	-3.20
4	6.20	17.90	18.35	8.75	21.80	19.60	2.55	3.90	1.25
5	3.25	15.55	16.95	3.55	11.00	16.90	0.30	-4.55	-0.05
6	8.10	19.65	48.05	11.30	30.65	82.30	3.20	11.00	34.25
7	11.35	28.90	46.45	12.35	28.60	43.25	1.00	-0.30	-3.20
8	17.75	70.25	93.40	17.25	42.90	58.00	-0.50	-27.35	-35.40
9	8.15	17.90	74.50	7.40	33.55	42.50	-0.75	15.65	-32.00
10	16.90	30.35	42.50	13.15	45.55	61.20	-3.75	15.20	18.70
11	11.05	39.25	115.40	19.05	62.40	237.85	8.00	23.15	122.45
12	31.70	95.30	168.90	60.95	130.50	217.10	29.25	35.20	48.20
13	46.85	218.30	362.85	68.65	264.75	399.60	21.80	46.45	36.75
14	27.00	74.55	122.65	16.40	47.35	165.80	-10.60	-27.20	43.15
15	26.20	56.40	126.80	55.75	73.90	237.80	29.55	17.50	111.00
16	9.50	31.85	45.00	12.15	44.90	65.25	2.65	13.05	20.25

<u>Relax 2</u>:

Subject	Left Temp	Left Cent	Left Par	Right Temp	Right Cent	Right Par	Asymm. Temp	Asymm. Cent	Asymm. Par
1	30.95	98.50	192.45	24.40	79.75	102.90	-6.55	-18.75	-89.55
2	26.90	43.85	114.70	35.20	55.90	141.90	8.30	12.05	27.20
3	22.25	45.35	50.40	25.25	57.50	54.30	3.00	12.15	3.90
4	5.55	16.55	17.40	6.05	18.75	17.40	0.50	2.20	0.00
5	2.70	14.00	15.85	3.40	12.40	16.65	0.70	-1.60	0.80
6	6.70	22.20	46.35	8.95	23.60	76.70	2.25	1.40	30.35
7	12.10	29.00	45.00	12.30	30.60	53.50	0.20	1.60	8.50
8	17.50	50.70	67.90	21.70	63.80	66.65	4.20	13.10	-1.25
9	10.30	32.95	86.10	9.20	61.80	45.70	-1.10	28.85	-40.40
10	11.75	31.90	52.10	18.90	38.50	64.55	7.15	6.60	12.45
11	13.80	39.95	96.15	17.10	52.00	166.35	3.30	12.05	70.20
12 *									
13	39.55	172.05	403.20	68.65	241.20	447.30	29.10	69.15	44.10
14	45.00	116.45	155.80	25.05	70.60	213.95	-19.95	-45.85	58.15
15	38.45	90.95	224.50	58.15	113.35	261.60	19.70	22.40	37.10
16	12.15	36.95	72.40	16.20	42.10	77.00	4.05	5.15	4.60

* Data unavailable due to hardware failure.

TABLE 10

Reading Condition: Median Alpha (watts).

Hemisphere->	Left			Right			Arousal Asymm. (Right - Left)		
Location->	Temp	Cent	Par	Temp	Cent	Par	Temp	Cent	Par
Subject									
1	7.05	13.75	12.65	8.50	20.85	16.75	1.45	7.10	4.10
2	13.65	24.80	40.75	15.55	21.55	38.15	1.90	-3.25	-2.60
3	6.80	14.05	29.65	19.25	24.05	31.00	12.45	10.00	1.35
4	6.80	13.50	14.65	6.20	11.85	14.60	-0.60	-1.65	-0.05
5	4.25	13.60	14.95	4.40	11.50	12.05	0.15	-2.10	-2.90
6	5.00	10.05	15.85	7.20	15.75	19.15	2.20	5.70	3.30
7	5.65	9.95	10.50	5.60	9.95	9.65	-0.05	0.00	-0.85
8	10.05	30.65	47.50	11.35	27.05	35.10	1.30	-3.60	-12.40
9*									
10	7.85	9.65	12.05	8.05	12.45	15.30	0.20	2.80	3.25
11	3.95	9.60	12.70	5.70	11.90	16.55	1.75	2.30	3.85
12	20.20	46.10	93.80	46.30	57.90	80.50	26.10	11.80	-13.30
13	19.00	91.15	192.30	23.75	79.55	103.90	4.75	-11.60	-88.40
14	4.65	7.05	7.35	4.20	6.70	8.75	-0.45	-0.35	1.40
15	10.50	30.25	49.75	17.15	46.30	58.75	6.65	16.05	9.00
16	7.30	10.60	16.80	7.50	12.90	15.35	0.20	2.30	-1.45

* Data unavailable due to hardware failure.

TABLE 11

Correlations Between Arousal Asymmetry in Lexical Decision (LD) Task and Other Conditions.

LD Task		Other Condition		Correlation	
Recording Time	Recording Location		Recording Location	All Ss	Excluding Outlier (S-)
Pre-stimulus	Temporal	Relax 1	Temporal	0.72**	--
Pre-stimulus	Temporal	Relax 2	Temporal	0.12	--
Pre-stimulus	Temporal	Read	Temporal	0.63**	0.50* (S3,12)
Pre-stimulus	Central	Relax 1	Central	0.37	0.62** (S13)
Pre-stimulus	Central	Relax 2	Central	0.06	--
Pre-stimulus	Central	Read	Central	0.77**	--
Pre-stimulus	Parietal	Relax 1	Parietal	0.49*	--
Pre-stimulus	Parietal	Relax 2	Parietal	0.64**	--
Pre-stimulus	Parietal	Read	Parietal	-0.16	--
Post-stimulus	Temporal	Relax 1	Temporal	0.70**	--
Post-stimulus	Temporal	Relax 2	Temporal	0.51*	--
Post-stimulus	Temporal	Read	Temporal	0.70**	--
Post-stimulus	Central	Relax 1	Central	0.58*	--
Post-stimulus	Central	Relax 2	Central	0.65**	--
Post-stimulus	Central	Read	Central	0.29	--
Post-stimulus	Parietal	Relax 1	Parietal	0.34	--
Post-stimulus	Parietal	Relax 2	Parietal	0.42	--
Post-stimulus	Parietal	Read	Parietal	-0.39	--

* $p < 0.05$
**$p < 0.01$

perceptual asymmetry (i.e., pre-stimulus temporal and pre-stimulus central) are also correlated with arousal asymmetries measured at the same locations during the Relax 1 or Read conditions (see Figures 9 through 12). Since both of these conditions occurred prior to the lexical decision task, the correlations suggest that the arousal asymmetry during the lexical decision task existed prior to performance of this task. This supports Levy et al.'s (1983) suggestion that arousal asymmetry may be individually characteristic and stable across conditions.

This claim is further bolstered by the presence of a number of other significant correlations betweeen arousal asymmetry during the lexical decision task and that during other conditions. Pre-stimulus parietal arousal asymmetry is significantly related to parietal arousal asymmetry during either of the Relax conditions. In addition, post-stimulus temporal or central arousal asymmetry is significantly related to arousal asymmetry at the same locations during other conditions.

The analysis of the relationship between arousal asymmetries measured during the Relax and Read conditions also provided evidence of substantial consistency in arousal asymmetry across conditions. As can be seen in Table 12, there is a strong relationship for all three recording locations between arousal asymmetry measured during Relax 1 and Relax 2. The correlations here are among the highest in the data. For temporal and central locations, there is also evidence of a relationship between arousal asymmetry measured during the Relax 1 condition and the immediately following Read condition. For the temporal location, there is also a relationship between Relax 2 and Read.

H. Analysis of the Relationship Between Perceptual Asymmetry and Arousal Asymmetry During Relax and Read Conditions

Since there was evidence of substantial relationships between arousal asymmetries during the lexical decision task and those measured during other conditions, it was of interest to examine whether perceptual asymmetries during the lexical decision task also correlated with arousal asymmetries in other conditions. The presence of such relationships would indicate that perceptual asymmetry in a particular task might be predictable from measurements of arousal asymmetry taken in other conditions. As can be seen in Table 13, there is evidence of a relationship between perceptual asymmetry and temporal Relax 1 or 2 arousal asymmetry, although outliers must be excluded for these relationships to be significant. These relationships are illustrated in Figures 13 and 14. These relationships provide further evidence for the notion that between-individual variation in perceptual asymmetry is related to characteristic, individual arousal asymmetry.

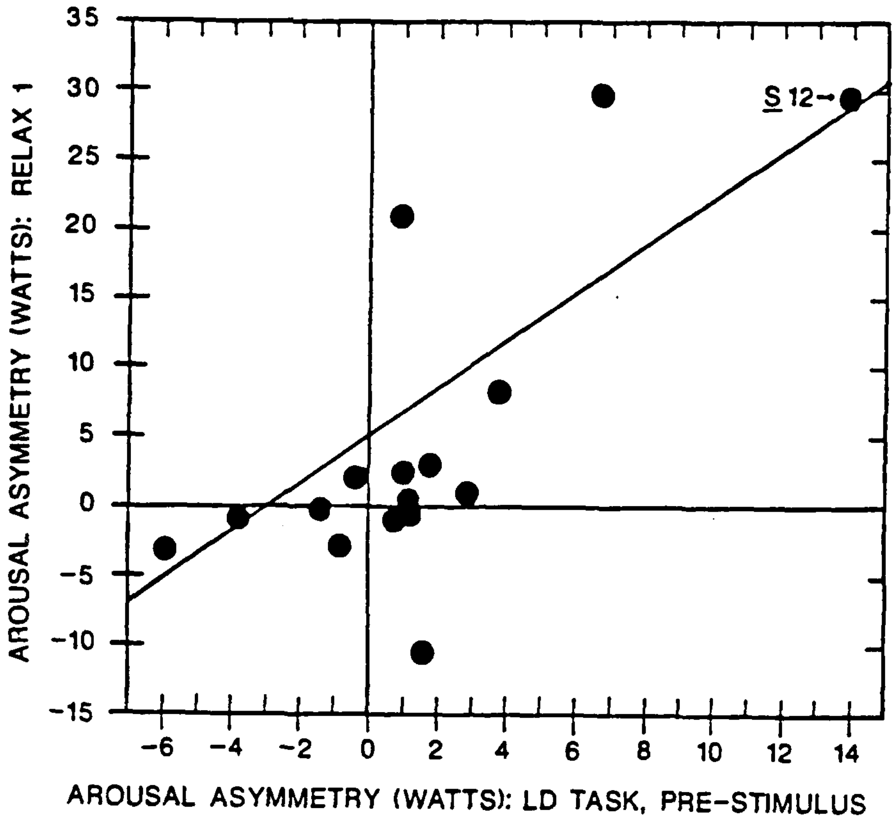

Figure 9. The Relationship Between Pre-stimulus Arousal Asymmetry During the Lexical Decision Task at the Temporal Locations and Arousal Asymmetry During the Read Condition at the Same Locations.

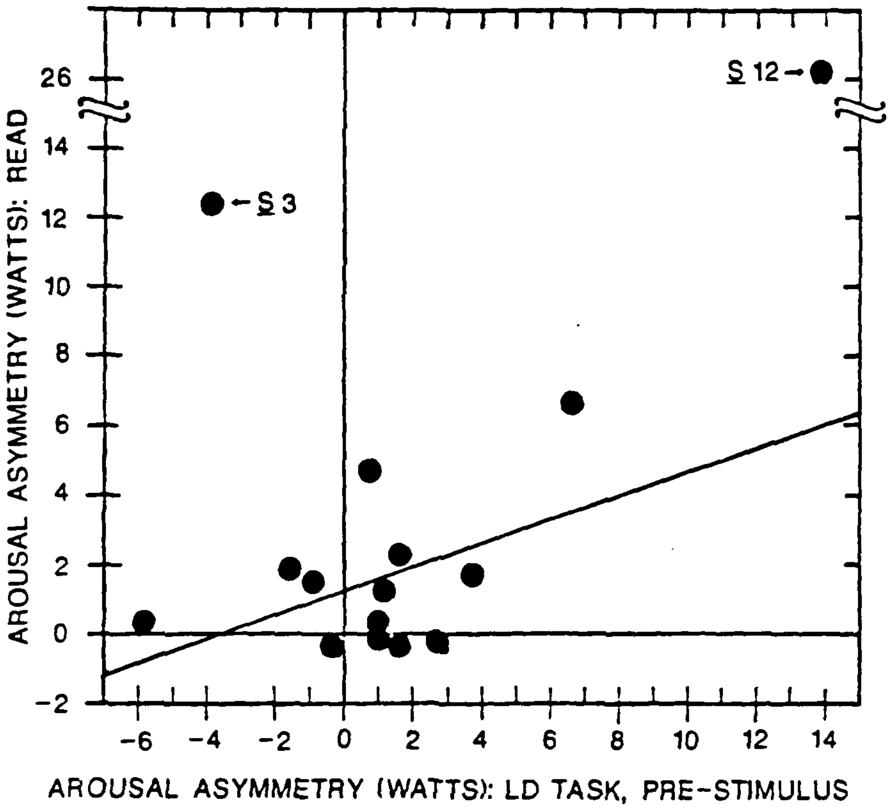

Figure 10. The Relationship Between Pre-stimulus Arousal Asymmetry During the Lexical Decision Task at the Temporal Locations and Arousal Asymmetry During the Relax 1 Condition at the Same Locations.

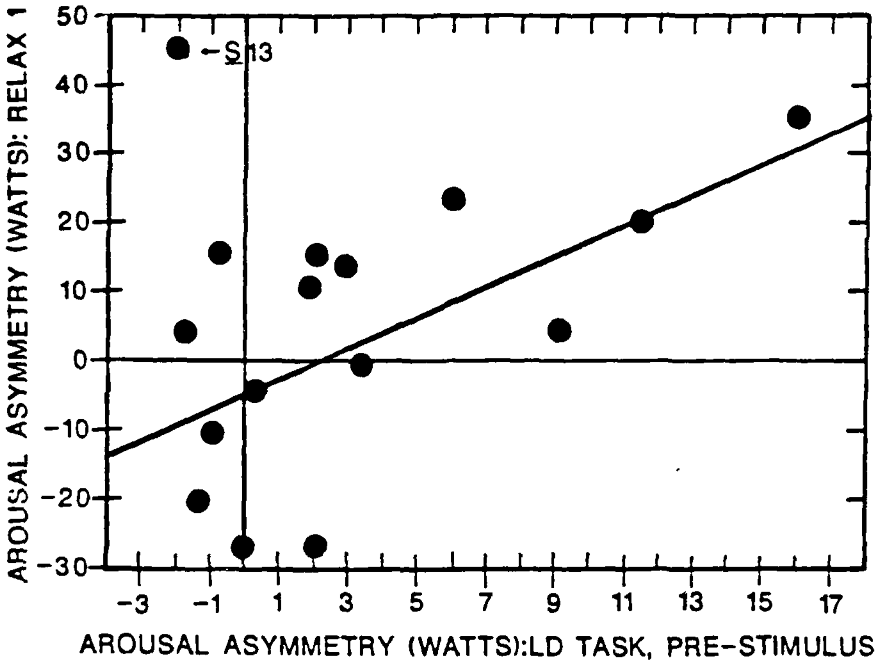

Figure 11. The Relationship Between Pre-stimulus Arousal Asymmetry During the Lexical Decision Task at the Central Locations and Arousal Asymmetry During the Read Condition at the Same Locations.

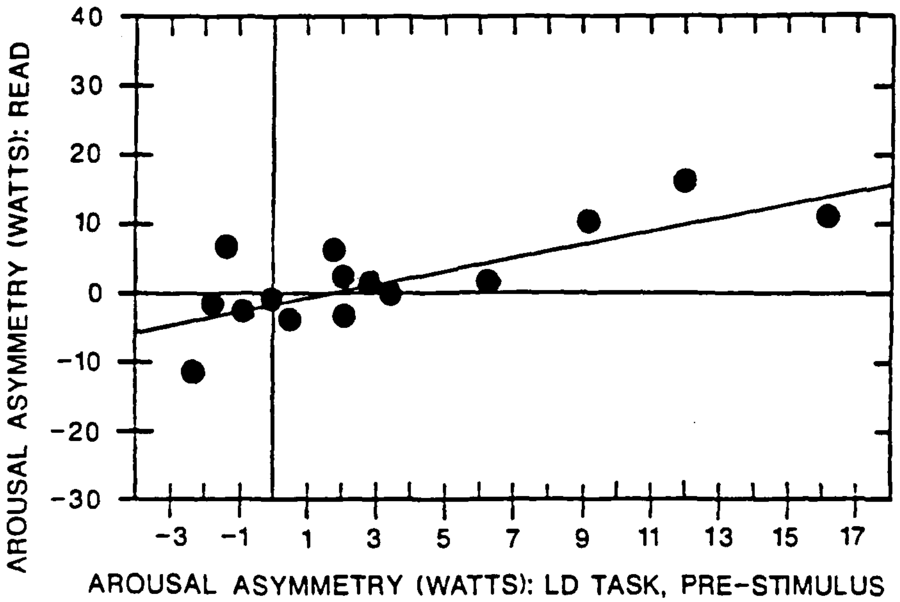

Figure 12. The Relationship Between Pre-stimulus Arousal Asymmetry During the Lexical Decision Task at the Central Locations and Arousal Asymmetry During the Read Condition at the Same Locations.

TABLE 12

Correlations Between Arousal Asymmetry in Relax and Reading Conditions.

			Correlation		
Recording Location	Condition 1	Condition 2	All Ss	Excluding Outlier	(S-)
Temporal	Relax 1	Relax 2	0.84**	--	
	Relax 1	Read	0.65**	0.74**	(S3)
	Relax 2	Read	0.41	0.76**	(S3)
Central	Relax 1	Relax 2	0.77**	--	
	Relax 1	Read	0.09	0.55*	(S13)
	Relax 2	Read	-0.29	--	
Parietal	Relax 1	Relax 2	0.87**	--	
	Relax 1	Read	0.01	--	
	Relax 2	Read	-0.19	--	

* $p < 0.05$
**$p < 0.01$

TABLE 13

Correlations Between Perceptual Asymmetry and Arousal Asymmetry During Relax and Reading Conditions.

Measure of Arousal Asymmetry	Correlation All Ss	Excluding Outlier (S-)
Temporal Location		
Relax 1	0.31	0.57* (S12, 13)
Relax 2	0.28	0.50* (S13)
Read	-0.13	--
Central Location		
Relax 1	0.13	--
Relax 2	0.15	--
Read	0.12	--
Parietal Location		
Relax 1	0.28	--
Relax 2	0.12	--
Read	0.15	--

* $p < 0.05$

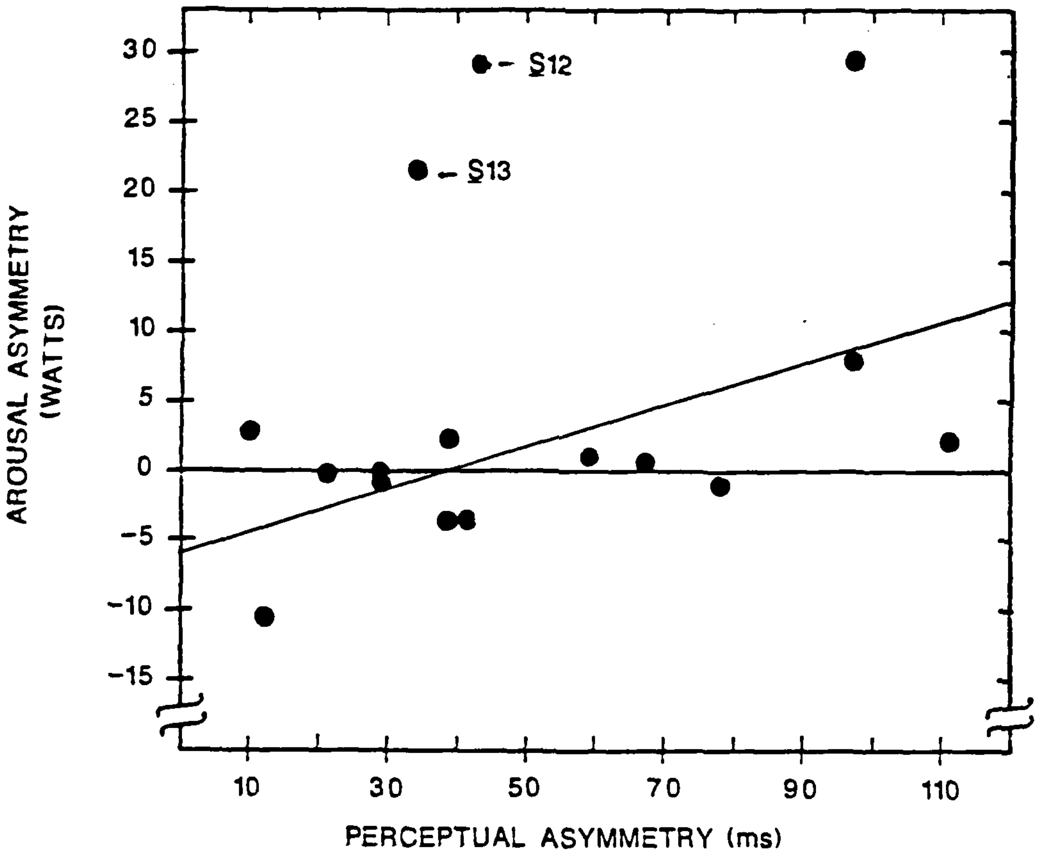

Figure 13. The Relationship Between Perceptual Asymmetry During the Lexical Decision Task and Arousal Asymmetry During the Relax 1 Condition at the Temporal Locations.

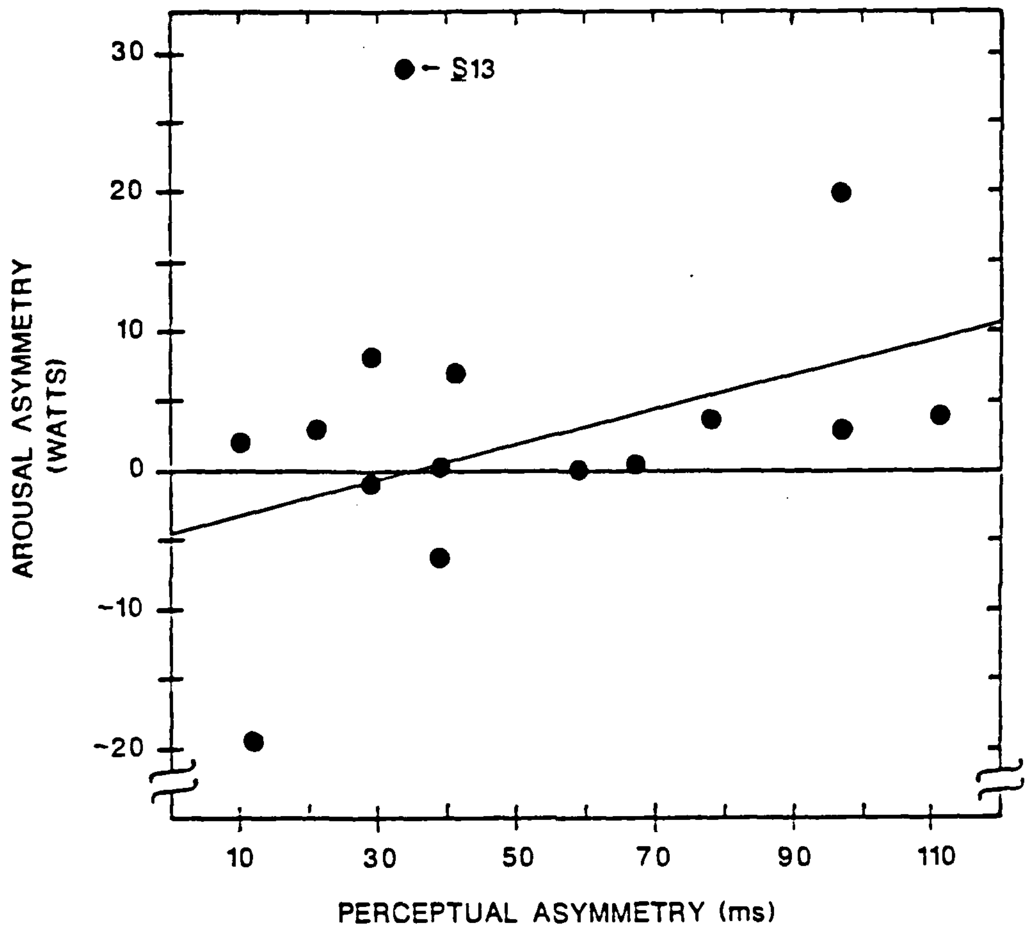

Figure 14. The Relationship Between Perceptual Asymmetry During the Lexical Decision Task and Arousal Asymmetry During the Relax 2 Condition at the Temporal Locations.

SECTION V

CONCLUSIONS, RECOMMENDATIONS, AND IMPLICATIONS

A. Theoretical Conclusions

The purpose of the present research was to examine the relationship between individual perceptual asymmetry and individual arousal asymmetry. When right-handed individuals perform a language-related task such as the lexical decision task used here, a perceptual asymmetry in the form of a right visual field advantage is generally observed. This is consistent with the idea that the left hemisphere (to which right visual field stimuli project) is specialized for language-related processing. There is also generally considerable variation between individuals in the magnitude of this perceptual asymmetry. The present research investigated the hypothesis that this variation was related significantly to between-individual variation in arousal asymmetry, as Levy, Heller, Banich, and Burton (1983) have proposed.

In general, the present research supports the proposal of Levy et al. (1983). A first major conclusion is that, during performance of a lexical decision task, right-handed individuals do exhibit asymmetries in arousal, the magnitude and nature of which vary between individuals. Some individuals have higher left hemisphere arousal, some individuals exhibit little arousal asymmetry, and some exhibit an arousal asymmetry in the form of higher right hemisphere arousal, even during performance of a task supposedly dependent upon the left hemisphere.

A second major conclusion is that in language-related tasks, there is a significant relationship between individual arousal asymmetry and individual perceptual asymmetry. In the present research, this relationship is significant when arousal asymmetry is measured in terms of electroencephalographic (EEG) activity over certain cerebral locations during certain intervals of task performance. Arousal asymmetry measured at the temporal location just prior to stimulus onset was significantly related to perceptual asymmetry.

Since the pre-stimulus interval is one in which attentional processes preparatory to stimulus processing are believed to occur, the present results would tend to confirm Kinsbourne's (1973) hypothesis that attentional biases are related to perceptual asymmetry. However, the present results suggest that attentional biases alone do not determine perceptual asymmetry. Individuals who appeared to have a more highly aroused right hemisphere did not exhibit a left visual field advantage, as might be expected if attentional bias alone determined perceptual asymmetry. When arousal asymmetry favored the right hemisphere, perceptual asymmetry still favored the right visual field, although the magnitude of this advantage was sometimes small. When arousal asymmetry favored the left hemisphere, the perceptual asymmetry favoring the right visual field tended to be larger. There is some suggestion in the data that the above relationship may not be valid when overall arousal level is relatively low.

A third major conclusion is that there is some evidence that individual arousal asymmetry is a stable, individual characteristic, although further research is necessary to investigate this. Individual arousal asymmetry measured at the temporal location during the pre-stimulus interval was significantly related to arousal asymmetry measured at the same location during different conditions that both preceded and followed the lexical decision task. Of particular interest is evidence that arousal asymmetry measured during a relaxation interval either preceding or following the lexical decision task was related to perceptual asymmetry during that task. This suggests the possibility that arousal asymmetry measured in very simple conditions prior to performance of a more complex visual task can be used to make predictions about certain aspects of performance during the more complex task.

B. Recommendations

The major recommendation of the present research is for additional research that will clarify and expand the usefulness of the present results for addressing performance-related problems. The present results suggest a number of important research areas. One set of questions has to do with the stability of both individual arousal asymmetry and individual perceptual asymmetry across time and tasks. The present results are consistent with the idea that individual arousal asymmetry is stable over time. However, this notion requires further confirmation using measurements separated by larger intervals of time. For example, comparisons might be made of measurements of individual arousal asymmetry separated by daily or weekly intervals. If arousal asymmetry is found to be highly stable over time, then this will facilitate the measurement of individual arousal asymmetry for use in predicting performance-related variables.

Similarly, it seems important to examine whether individual perceptual asymmetry is in some sense "characteristic" and stable over time. Is an individual's perceptual asymmetry during a lexical decision task related to his/her perceptual asymmetry during other language-related tasks? If both arousal asymmetry and perceptual asymmetry are determined to be relatively stable, then this will facilitate the prediction of performance quality over a wider range of task conditions.

A second area recommended for research has to do with further investigation of the relationship between individual arousal asymmetry and certain personality variables. One of the more intriguing reasons for investigating the relationship between arousal asymmetry and perceptual asymmetry was the possibility that arousal asymmetry might also be predictive of certain aspects of personality. Levy et al. (1983) review clinical evidence suggesting that unusual arousal asymmetries are related to tendencies toward affective disorders (e.g., mania, depression). They found experimental evidence indicating that arousal asymmetry was related to certain performance-related attitudes. The possibility of a relationship between arousal asymmetry and personality characteristics is certainly intriguing, and has important implications for understanding individual differences.

A third general area for research might focus on the relationship between arousal asymmetry and performance in other task conditions. The present results suggest that in language-related tasks, arousal asymmetry interacts with left hemisphere specialization in determining the magnitude of the right visual field advantage. One question of interest is whether there is a similar interaction during performance of tasks for which the right hemisphere is specialized, e.g., certain visuospatial tasks such as face recognition, for which a left visual field advantage is typically observed. Does arousal asymmetry help determine the magnitude of the left visual field advantage in such tasks? What happens in tasks for which neither hemisphere is specialized? In such conditions, does arousal asymmetry alone determine perceptual asymmetry?

A fourth, recommended area for research focuses on certain methodological issues related to the electrophysiological measurement of individual differences and to the measurement of arousal asymmetry. The present research assessed arousal asymmetry in terms of ongoing EEG activity using conventional data analysis procedures. Although this approach proved fruitful, it seems important to examine and compare other approaches to data analysis, so that the most robust and reliable measures can be applied to further investigation of individual differences. There is a variety of alternative ways of analyzing alpha activity and, in addition, the fruitfulness of analyzing beta activity, which increases with arousal, should be explored. The usefulness of the evoked potential (as opposed to ongoing EEG) might also be investigated. Comparisons such as these are among the objectives of an A.R.I.-sponsored program at Georgia Tech beginning during August, 1986.

C. Applied Implications

The present work represents basic research. As such the results must be replicated and tested for generalizability before they are applied to solving practical problems in the real world. Much of the research recommended previously is necessary to determine such reliability and generalizability. It is, nevertheless, appropriate at this time to consider the possible problem areas to which the results might be applied and their potential usefulness.

The work applies most directly to the prediction of certain aspects of the quality of individual human performance in conditions dependent upon fast, accurate processing of visual information. Such conditions are commonly faced by military operators who must use visual information to guide subsequent decisions and responses, for example, radar operators, pilots, or operators of complex systems of many types. The operation of such systems generally involves the monitoring of a complex, rich visual environment which includes numerous visual displays. Critical visual signals may appear on any of the displays. Frequently, these signals appear to the left or right of where the operator is actually focusing at a given moment, i.e., in the operator's left or right visual field. The present results have implications for developing better measurement techniques for predicting the relative speed with which an individual operator can respond to critical stimuli appearing in the left versus right visual field.

The results suggest that the speed of performance based on left versus right visual field stimuli may be predictable from measurements obtained prior to task performance in much less complex conditions. In the present study, measurements of arousal asymmetry obtained during a four minute period of relaxation prior to task performance were significantly related to the differential speed of left versus right visual field reaction time during task performance. The stability of arousal asymmetry and the generalizability of its impact across tasks require further investigation before the relationship between individual arousal asymmetry and aspects of individual performance is applied to practical problems. However, the evidence of such a relationship suggests possibilities for using pre-task measurements of arousal asymmetry to better match individual capabilities to task demands. The present results point to an approach for screening task candidates so as to eliminate candidates who appear to have arousal asymmetries potentially detrimental to task performance, and to select candidates whose arousal asymmetries may facilitate performance.

As has been previously discussed, there is also the possibility that individual arousal asymmetry may be related to certain other aspects of individual personality and performance style. Unusual arousal asymmetries within apparently "normal" individuals may be related to styles of behavior which, although functional in most conditions, may be dysfunctional in the demanding, stressful conditions of most military environments. Measurement of arousal asymmetry may therefore have potential usefulness in discriminating between individuals who vary in their capabilities to withstand the demands of such environments.

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APPENDICES

APPENDIX A

Hardware Design and Filter Specifications

When designing the EEG data sampling and recording system, several issues were given careful consideration. First, it was desirable that the signal to noise (S/N) ratio be kept as high as possible. Second, signals were to be frequency band-limited (via a filter) to prevent aliasing, but, for purposes of data analysis, it was desirable that linear phase be preserved over the band of interest. Finally, a sampling rate had to be chosen so that all of the necessary signal information could be preserved while not overfilling the memory of the PDP 11/23 computer that was to store the raw data.

S/N Ratio

The manufacturers of the EEG machine (Grass Company) specify a noise voltage of about 2 uV peak-to-peak referred to a shorted input. Furthermore, EEG sensor outputs are seldom over 100 uV. From this, the approximate value for the system S/N was determined to be as follows:

$$S/N = 20 \log_{10} \left(\frac{\text{max signal voltage}}{\text{noise voltage}} \right)$$

$$= 20 \log \frac{100}{2} = 20 \log 50 = 34 \text{ dB}$$

Thus, it was desirable that the digitizer have a dynamic range of at least thirty-four dB.

In a linear A-D, the n^{th} bit represents a magnitude of 2n times the magnitude of the least significant bit (LSB). Thus the dynamic range of an n bit A-D is

$$DR(dB) = 20 \log (2\ ) = 20\ n\ \log 2$$

$$\approx 6\ n$$

This suggested that a six-bit digitizer was sufficient to provide adequate dynamic range. Since the PDP-11/23 has sixteen bit words and eight bit bytes, an eight bit A-D converter was used.

Filter Specifications

The purpose of the anti-aliasing filter is to eliminate any high frequency energy that could be aliased into the baseband signal of interest during the sampling process. For the present application, it was desirable that linear phase be preserved over the frequency band from 0-50 Hz.

With analog filters, a desirable (i.e.,flat) amplitude response is usually accompanied by an undesirable phase response, or a desirable phase response by an undesirable amplitude response. In filter design, there is a tradeoff between the degree of flatness (ripple) in the amplitude response and the degree of linearity of the phase response. For this application, the elliptic-type filter provided a good compromise. This type of filter has a flat passband and a linear phase characteristic over ten percent of the bandwidth.

A fourth-order filter was designed with a bandwidth of about 500 Hz and ultimate stopband attentuation of 45 dB. The sampling rate was set at 512 Hz. As a result, the frequencies at which the aliased signals are higher than the A-D converter quantization noise are all above 50 Hz, i.e., the linear phase region is alias-free.

Overall Data Volume

The general equation for data volume is

$$V = R \times W \times T \times C$$

where
V = total data volume in bytes
R = sampling rate in samples/second
W = the number of bytes per sample
T = total time in seconds
C = number of channels being sampled

For the system described above, the data volume per time given 8 bit samples and 8 channels is

$$\frac{V}{T} = 512 \times 1 \times 8 = 4096 \text{ bytes/second}$$

Since the PDP-11/23 has 256 K memory it is able to accummulate data for a maximum of

$$T = \frac{256 \times 10^3}{4096} = 64 \text{ seconds}$$

Summary

A data acquisition system was designed which allows reconstruction of eight channels of EEG data out to 50 Hz. Time domain distortion of the data has been minimized by using a linear-phase, anti-aliasing filter. This filter is an elliptic type with a bandwidth of 500 Hz and linear phase to 50 Hz. Sampling is performed at 512 Hz per channel to keep aliased components out of the 0-50 Hz region.

APPENDIX B

Text Passages and Questions Used in the Read Condition

Passage A

At five-thirty on the afternoon of August 29, 1907, a steelworker named Ingwall Hall was perched high on the partially constructed south cantilver arm of the Quebec Bridge, a few miles from Quebec City. The bridge was to have a span of eighteen hundred feet when completed--the longest in the world. The first whistle signaling the end of the work day had just blown, and Hall was waiting out the few minutes before the final whistle that would send the men on the structure home for the night.

Instead of the final whistle, the workers heard a loud report, like a cannon shot. Two compression chords in the south anchor arm of the bridge had failed, either by the rupture of their latticing or by the shearing of their latticing rivets, and as the distress of mortally tortured steel spread through the entire superstructure the nineteen thousand tons of the south anchor and cantilever arms and the partially completed center span thundered down onto the banks of the St. Lawrence River and into the water the bridge had been designed to cross. One eyewitness likened the collapsing columns to 'ice pillars whose ends were rapidly melting away'.

Swallowing water and fighting the river's sudden turbulence, Hall had to struggle in order to breathe. After a few long minutes, a rescue boat reached Hall, and he was dragged aboard. He had lost two fingers, but of the eighty-six men on the bridge when it went down, he was one of only eleven who survived.

No bridge collapses quickly. Just as the safe completion of a bridge is measured in years, the failure of a bridge can be reckoned in the same way. Though the chaotic physical dismemberment of the south arm of the Quebec Bridge took no more than fifteen seconds, the more orderly prelude to the catastrophe began long before.

It began in the summer of 1897, when the consulting engineer Theodore Cooper attended the annual convention of the American Society of Civil Engineers in Quebec City. A former director of the society, Cooper was one of the most respected bridge builders of the time. He made an excursion to the proposed site of the Quebec Bridge and within a week expressed an interest in giving the Quebec Bridge Company the benefit of his expertise.

Cooper's tender of interest was hardly unbidden. The Quebec Bridge Company had been sounding out American bridge engineers as consultants because its own chief engineer, Edward A. Hoare, had never worked on a bridge with a span longer than three hundred feet. Cooper was a proud, confident man, fiercely devoted to his calling. He had been graduated as a civil engineer from the Rensselaer Institute (now Rensselaer

Polytechnic) in 1858 at the age of nineteen. Enlisting in the Navy in 1861, he served as an assistant engineer of the gunboat Chocura for the last three years of the Civil War, then moved on to a teaching post at the United States Naval Academy. After a tour of duty in the South Pacific, he resigned from the Navy in July 1872. In May of that year, Capt. James Eads appointed Cooper the inspector of steel manufacturing for Ead's most important engineering work, the St. Louis Bridge.

If the Navy laid the groundwork for Cooper's career, the St. Louis Bridge launched it along a high trajectory. Captain Eads moved Cooper up quickly, placing him in charge of erection at the bridge, which was the most ambitious use of the cantilever method of erection yet attempted. Cooper performed his duties admirably--once going without sleep for sixty-five hours during a crisis, another time wiring Eads at midnight to warn him that the arch ribs were rupturing, a potentially disastrous condition that was remedied by following the instructions Eads immediately wired back. Upon completion of the work in 1874, Cooper found himself much in professional demand. By 1879, after resigning as the superintendent of Andrew Carnegie's giant Keystone Bridge Company in Pittsburgh, Cooper was able to set up as an independent consulting engineer in New York.

The projects he undertook there were notable and prestigious. His works included the Seekonk Bridge in Providence, the Sixth Street Bridge in Pittsburgh, and the Second Avenue Bridge in New York. He moved through the most rarefied atmosphere of his profession, but unlike his mentor Eads, he never oversaw a truly heroic masterwork. The Quebec Bridge, viewed in that light, was irresistible to Cooper. He said the bridge would be his last work. It would stand as the crowning achievement to an elegant career.

Almost two years would go by before Cooper's affiliation with the Quebec Bridge Company became formal. The financially troubled company had a history of moving slowly--or not at all. Incorporated by an Act of Parliament in 1887, it had accomplished virtually nothing in its first eleven years. In March 1899, officials of the company met with Cooper in New York and arranged for him to review the bids for the long-awaited bridge contracts. All prospective contractors' plans and tenders were sent to him, as well as clear instructions on how he should proceed. He was especially urged to keep in mind the weak financial position of the Quebec Bridge Company.

The Quebec Company had been in close touch with the Phoenix Bridge Company of Phoenixville, Pennsylvania, since 1897, and the Phoenix Company had already submitted preliminary plans for the bridge. Now that the bidding was open, the Quebec Company's desire to give the Phoenix Company the contract for the superstructure was barely concealed.

On April 14, 1899, John Sterling Deans, the chief engineer of the Phoenix Bridge Company wrote to Edward Hoare, his counterpart in Quebec: 'Dear Mr. Hoare--Mr. Szlapka [Phoenix's chief design engineer] and I were with Cooper the greater part of yesterday, and you will be glad to learn that there was not a single vital or important criticism or mistake found in our plans. . . . Mr. Cooper, however, somewhat upset me, by making the following remark, which of course I understood was entirely personal and without any full knowledge of the situation. He said: 'Well, Deans, I believe that all the bids will probably overrun the amount which the Quebec Bridge Company can raise, and that the result will be . . . that all of the bids will be thrown out and a new tender asked on revised specifications and plans.' Mr. Cooper undoubtedly desires to be perfectly fair, but therefore, that you will give his report the most careful scrutiny, and get it in the right shape before it is submitted.

There were more collegial letters between Phoenixville and Quebec, and both Deans and Hoare stayed in close touch with Cooper. Later Cooper would maintain that no pressure had been brought to bear on him. In any event, on June 23, 1899, he sent his findings to the Quebec Bridge Company. 'I therefore hereby conclude and report,' he wrote, 'that the cantilever superstructure plan of the Phoenix Bridge Company is the 'best and cheapest' plan and proposal.

Those three words--'best and cheapest'--became a touchstone for Cooper in his approach to the bridge. His subsequent letters to Quebec and Phoenixville are seasoned with references to the fiscal consequences of major design decisions. None of the parties involved ever placed cost before safety outright, but their aim was to clearly build a bridge that could bear the twin loads of its own mechanical burden and the Quebec Bridge Company's financial burden.

The Quebec Company had no cause to be dissatisfied with Cooper's scrupulous concern for its ledger books--and had every reason to be confident of his ability to oversee the building of a good bridge. On May 6, 1900, Cooper was appointed the company's consulting engineer for the duration of the work. He had become, finally, the master builder on a project of historic magnitude.

Five days before his formal appointment on May 1, Cooper exercised his authority by recommending that the span of the bridge be lengthened from sixteen hundred feet to eighteen hundred feet. His explanation for this major design change revealed an attentiveness to both engineering and expense. Piers constructed in deeper water would be subject to the heavy ice floes of the main channel. Closer to shore, they would be less vulnerable--and quicker to build, speeding up the completion of the entire work by at least one year. The change would also make the bridge the world's longest. To keep down the increased cost of steel in the superstructure for an eighteen-hundred foot span, Cooper recommended another major design change: modified specifications that would allow for higher unit stresses.

His recommendations were approved at Quebec almost as a matter of course. And then, for the next three years--as work proceeded on the superstructure, the anchorages, and the approach spans--practically nothing was done to prepare for the engineering difficulties posed by the eighteen-hundred-foot span and the higher allowable stresses. Once again, money was the root of inaction. Short of funds as usual, the Quebec Bridge Company was making no promise to anybody about its capacity to pay for the bridge's superstructure once the preliminary work was done. For all the goodwill between Phoenixville and Quebec, the Phoenix Bridge Company was politely declining to enter into a contract until payment might be assured.

And so, while the huge size of the bridge cried out for preliminary tests and research studies, none were conducted during the long slack period between 1900 and 1903. It was not in the interests of the Phoenix Bridge Company to go out-of-pocket on research costs it might never recoup, and it was plainly impossible for the Quebec Bridge Company to provide the funds. An unspoken assumption became necessary instead: Theordore Cooper's experience and authority were suffient to confer successs upon the untested work.

Then in 1903 the Canadian government guaranteed a bond issue of $6.7 million to pay for the work. With that, the torpor enveloping the project turned into humming activity. Phoenix and Quebec entered into serious contract discussions while design engineers and draftsmen struggled to meet the urgent demand for detailed drawings.

Three years of opportunity for deliberate preparation had been lost. In the rush to provide drawings so that the steel for the bridge could be fabricated with little loss of time, there was no recomputation of assumed weights for the bridge under the revised specifications. It was an oversight of critical importance, and Theodore Cooper did not intervene. He decided to accept the theoretical estimates of weight that the Phoenix Bridge Company had provided.

Questions on Passage A:

1. The article is about a bridge built in Quebec. (True)
2. When the bridge collapsed, about half of the people driving across were killed. (False)
3. The bridge was constructed about 1930. (False)
4. One of Cooper's finest previous accomplishements was a bridge build in St. Louis. (True)
5. The span of the bridge was shortened to increase its weight-bearing capability. (False)
6. The cost of the bridge was of major concern to Cooper and to the bridge company. (True)
7. Careful computation and research confirmed the quality of Cooper's design. (False)
8. Cooper was close to retirement when he undertook the bridge project. (True)

Passage B

Just before dawn broke over California last Friday, a prized bundle of radio signals began its arduous journey from outer space. Dispatched from the Voyager 2 spacecraft and traveling at the speed of light, the radio beam cut through the chilly suburbs of the solar system beyond Saturn, raced past the asteroid litter between Jupiter and Mars and then, after 2 hours, 44 minutes and 50 seconds of cosmic odyssey, touched huge dish antennas at three stations on planet Earth. The signal had become so weak during the 1.8 billion-mile trip that it measured a barely perceptible one-millionth of a billionth of a watt, but like the dying runner of Marathon, it had just enough strength to deliver its message. And it was a historic one: the mysterious, distant planet Uranus, swaddled in its halo of coal-black rings and shroud of blue haze, was not the drab orb it seemed from Earth, but rather a planet crackling with electromagnetic signals and dappled with orange smog, accompanied by moons once bristling with geologic activity and scarred with craters testifying to a violent past.

Waiting astronomers basked in their midwinter's night dream. The mission to Uranus, its slender rings and giant Shakesperian moons, Oberon and Titania, was humankind's first close look at the seventh planet in our solar system and its last for the millennium. Though some findings were too arcane for laymen, they sent normally staid scientists floating freely in their own inner space. Said project scientist Edward Stone of the California Institute of Technology, "This mission will be `the' great encounter of our lifetime."

For all of man's pride, it took a quirk of nature to make the view of Uranus possible. Launched on August 20, 1977, Voyager 2 had been ticketed only as far as Jupiter and Saturn. But a once-in-177-years alignment of the planets let NASA extend the itinerary: using the immense gravity of Saturn, the engineers at the Jet Propulsion Laboratory near Pasadena "slingshotted" Voyager toward Uranus and a Grand Tour of the planets (Voyager will reach Neptune in 1989). The craft began to explore Uranus afar in November, and by last week's flyby it had discovered 10 new moons around the planet, bringing to 15 the number of satellites in Uranus's retinue.

Like everything else in space, distance was relative. Last week the craft saw its quarry from only 50,679 miles above the planet's clouds. For NASA, it was a targeting feat equal to hitting a single atom from two football fields away. Traveling 10 times faster than a rifle bullet, Voyager threaded a path between the rings and the moons of Uranus and in six short hours collected more information on the planet than astronomers had amassed in the 205 years since it was discovered.

Overnight Uranus was transformed from an object of theory into one of fact. Discovered on a cool spring evening in 1781 by William Herschel, a German-born musician and amateur astronomer in England, the planet is visible enough through telescopes so that astronomers can infer its composition and history, as well as those of its moons. But the image from Earth is so dim that these theories have been somewhat unencumbered by facts. "It is a planet of nearly unfathomable mystery," says Bradford Smith of the University of Arizona, leader of Voyager's photo-interpretation team. Chief among those mysteries is how Uranus got tipped over. Unlike other planets, which spin on nearly vertical axes, Uranus rotates about a horizontal one, like a dying top. Astronomers speculate that it was knocked over by an object the size of Earth early in its 4.5 billion-year history. The collision might also have splashed part of the planet into space. "Material might have been spun out into a disc," says Stone, "and rings and satellites might have formed from this disc."

The rings, blacker than coal dust, are one of the true wonders of space. Unlike the wide, symmetrical bracelets of icy particles circling Saturn, rings around Uranus are warped, tilted and bizarrely elliptical, and can vary in width by dozens of miles. How the ring particles manage to stay in these odd patterns is one of Uranus's great puzzles, and Voyager has solved one piece of it: the craft spotted a pair of tiny "shepherd moons," which keep one ring's particles from dispersing. Together, the moons' gravitational pushes and pulls keep the particles in a tight orbit. Astronomers think each of the ten rings (Voyager discovered one new one) has a pair of shepherds nearby; the others may be discovered somewhere in Voyager's voluminous data.

At the weekend the rings had presented astronomers more enigmas; two reflected light differently from the others, suggesting they were made of different material, and some contained ripples. Scientists had thought they understood the rings' composition; they believed the rings consisted of methane, which had been blackened by radiation, or else were composed of carbon-rich material, a sort of primordial tar scavenged from outer space. But the rings with odd spectra made scientists wonder what they were made of. And JPL's Arthur L. Lane predicted that the "extremely interesting ripples in the rings will give the theoreticians a field day."

Voyager also discovered that Uranus's moons might have a violent and geologically active past. Oberon, the largest, has a small dark spot that looks suspiciously like a crater. A crater would support the idea that Uranus and its moons were the targets of speeding cosmic bullets long ago, one of which may have tipped over the planet. The sharp-eyed craft also discerned a chevron-shaped mark on Miranda and rough upland areas on Umbriel, the darkest satellite. Ariel shone with small bright spots, which might mean that the icy moon has a dark coating which, when punctured, throws white ice to the surface much as terrestrial volcanoes cough up lava. Titania also showed light splotches across its brown-gray face, which hinted that the moon might have been "resurfaced" by new material welling up from the core.

These signs of geologic activity were not what planetary scientists expected. But, said Laurence Soderblom of the U.S. Geologic Survey and member of the Voyager team, "we were surprised at Saturn. We were surprised at Jupiter. It's not surprising that we are surprised at Uranus."

Six of the new moons tease the scientific imagination. They are so black -- Smith describes them as "like big clumps of coal" -- that astronomers speculate they may be chunks of ring particles. If true, that would reinforce the theory that the rings and moons were formed from the same debris. Another curiosity is that six new moons all orbit within 8,500 miles of each other, hinting at still more violence in Uranus's past. "A likely possibility is that an interloper from outside the Uranus system came in and struck a once larger moon sufficiently hard to have fractured it," says JPL's Ellis Miner, assistant project scientist.

News about Uranus itself will continue to filter out as data are analyzed, but already a few surprises have emerged. The solar system's third largest planet -- four times the size of Earth -- had been thought to be as featureless as an aqua billard ball (methane in its atmosphere gives Uranus a bluish tinge). But last week Voyager spotted orange bands around the planet's pole which astronomers interpreted as photochemical haze not too different from the smog around JPL. Voyager also detected clouds in Uranus's atmosphere, which may fill a glaring blank in their list of Uranus's vital statistics: by tracking the clouds' rotations, they may finally learn how long it takes the planet to spin on its axis. The length of a Uranian day has been estimated at anywhere from 16 to 24 hours, and Voyager's data support the lower estimates.

What Voyager heard proved as valuable as what it saw. On the day before the closest encounter, Stone announced that the craft had finally detected radio noise from Uranus, which researchers interpret as evidence of a magnetic field around the planet. The noise resembled that made by electrons spiraling through a planet's magnetic field, and it was a welcome sound. For weeks astronomers had been puzzled by the silence around Uranus; it suggested that the planet lacked the magnetic field characteristic of other major planets. "Because we were looking for small bursts of radio noise, we didn't recognize a gradual increase in radio emissions," a sheepish Stone announced. "We didn't see the forest for the trees."

Finding a magnetic field around Uranus should tell astronomers something about what lies beneath the planet's cloud tops. Scientists believe that magnetic fields arise when the spinning, hot core of a planet acts as a dynamo, or generator. Thus the strength of the field should reveal the heat of the core and how fast it turns. Alternatively, the magnetism might be generated by a more exotic source: an electrically charged ocean on Uranus's surface. Whatever its origin, the magnetic field has already literally turned astronomer's ideas about Uranus on end:

it was tilted on its side by the dramatically large angle of 55 degrees, a configuration unique in the solar system and so far unexplained. All this from what untutored earthlings would recognize only as static.

"Uranus is not giving up its secrets easily," said Brad Smithlate last week, as he faced a pile of blurry photos of the planet. It will take months for astronomers to figure out what Voyager's 11 instruments were trying to tell them about the blue giant. The last close-up images of the planet, as Voyager sailed through the cold silence of outer space en route to Neptune, showed Uranus and its rings eerily backlit by the sun. The photo struck a bittersweet note at JPL, where the assembled scientists gloried in the successful encounter but realized that having barely said hello, it was time to bid Uranus farewell. With budget cuts performing the impossible -- checking the dreams of scientists -- Voyager was the last spacecraft that 20th-century man would send billions of miles to explore an unknown world at the edge of the solar system.

Questions on Passage B:

Please answer "true" or "false" for each statement.

1. Voyager 2 was launched about two years ago. (False)
2. The major mission of Voyager 2 was to explore Uranus. (False)
3. Voyager 2 is now heading further away from earth. (True)
4. Uranus can be seen through telescopes on earth. (True)
5. Uranus spins on an axis different from those of other planets. (True)
6. Uranus's rings have a perfectly round and symmetrical shape. (False)
7. The rings are of brilliant colors. (False)
8. There is evidence that Uranus's moons had a geologically active past. (True)

APPENDIX D

Handedness Inventory

Name____

Please indicate your prefeiences in the use of hands in the following activities by checking the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, check the "Always" column for the appropriate hand. For tasks in which you usually use a specific hand because it is more comfortable, but could use the other hand, check the "Mostly" column for the appropriate hand. For tasks in which either hand could be used without any differences in comfort or performance, check the "Either" column.

Some of the activities require both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the subject or task.

		(1) Always Left	(2) Mostly Left	(3) Either Hand	(4) Mostly Right	(5) Always Right
1	Writing					
2	Drawing					
3	Throwing					
4	Scissors					
5	Toothbrush					
6	Knife (without fork)					
7	Spoon					
8	Broom (upper hand)					
9	Striking Match (match)					
10	Opening box (lid)					
i	Which foot do you prefer to kich with?					
ii	Which eye do you use when using only one?					

APPENDIX E

Read Condition: Number of Correct Responses

Subject	Number Correct Responses (max = 8)
1	7
2	6
3	7
4	6
5	8
6	8
7	5
8	6
9	6
10	6
11	6
12	7
13	5
14	6
15	6
16	7
	$\bar{x} = 6.4$

APPENDIX C

Items used in Lexical Decision Task.

	Word	Frequency	Mean Concreteness	Corresponding Nonword
1.	SOUL	99	1.42	LOUS
2.	HOPE	99	1.50	POHE
3.	LUCK	46	1.55	CULK
4.	FEAR	99	1.79	RAFE
5.	CARE	99	1.87	CRAE
6.	MOOD	27	2.00	DOIM*
7.	SAKE	50	2.16	SKAE
8.	RISK	40	2.32	SKIR
9.	TIME	99	2.36	MOTE*
10.	MIND	99	2.39	NIMD
11.	ODDS	10	2.45	DODS
12.	EASE	50	2.45	AESE
13.	LACK	50	2.50	CLAK
14.	LIFE	99	2.50	EILF
15.	MYTH	8	2.55	HYMT
16.	CALM	50	2.61	LAMC
17.	GOAL	21	2.66	LOAG
18.	RATE	99	2.82	TROE*
19.	SORT	99	2.92	ROST
20.	HINT	29	3.00	NITH
21.	OATH	18	3.00	HOAT
22.	RULE	99	3.05	LEUR
23.	PLEA	10	3.08	LAPE
24.	HARM	50	3.21	MAHR
25.	ROLE	11	3.32	ORLE
26.	PLAN	99	3.34	NALP
27.	RUIN	50	3.34	NUIR
28.	WEST	99	3.39	TEWS
29.	DIET	27	3.39	TIED
30.	HOUR	99	3.45	HURE
31.	SPAN	13	3.50	NASP
32.	TYPE	99	3.53	PYTE
33.	TASK	50	3.55	KEST*
34.	RANK	50	3.58	NIRK*
35.	BULK	20	3.61	KULB
36.	SIZE	99	3.61	ZISE
37.	COST	99	3.63	STEC*
38.	FACT	99	3.66	CAFT
39.	BOND	50	3.68	BUND*
40.	YEAR	99	3.71	YARE
41.	DOSE	8	3.82	SADE*
42.	CODE	21	3.92	DOCE
43.	FOLK	50	3.95	KLOF
44.	SALE	50	3.97	LASE
45.	VIEW	99	4.00	WUVE
46.	FLAW	6	4.03	WALF

	Word	Frequency	Mean Concreteness	Corresponding Nonword
47.	POLL	17	4.03	LOLP
48.	CURE	46	4.05	RUCE
49.	TOWN	99	6.13	TWON
50.	LAND	99	6.24	NALD
51.	RACK	29	6.24	KARC
52.	CASH	46	6.29	CHIS*
53.	LAWN	37	6.32	WALN
54.	TOMB	22	6.39	BOMT
55.	SCAR	17	6.42	CRES*
56.	DUST	50	6.45	SUDT
57.	BOWL	50	6.45	WOLB
58.	TOOL	40	6.45	LOTE*
59.	MONK	20	6.50	KIME*
60.	TAIL	50	6.50	ALIE*
61.	FIRE	99	6.50	RIFE
62.	ROOT	50	6.55	OORT
63.	WING	99	6.58	NIWG
64.	SEED	50	6.61	DESE
65.	ROOF	99	6.66	RAFE*
66.	BEEF	20	6.66	FEBE
67.	HARP	20	6.68	PRAH
68.	DIRT	21	6.68	TRID
69.	PLUM	23	6.68	MULP
70.	COIN	50	6.71	NOIC
71.	PAIL	16	6.71	LAIP
72.	VEST	21	6.74	STEV
73.	WOOD	99	6.76	DWOE*
74.	PIPE	50	6.79	EIPP
75.	OVEN	29	6.79	VONE
76.	GOLD	99	6.79	DOLG
77.	RAIN	99	6.79	AIRN
78.	ROBE	31	6.82	BROE
79.	DESK	50	6.82	SKED
80.	VINE	38	6.84	NIVE
81.	NOSE	99	6.84	SONE
82.	POND	30	6.84	DONP
83.	MOSS	22	6.84	SIMS*
84.	CANE	19	6.87	NACE
85.	MULE	29	6.89	LUME
86.	TENT	50	6.92	ENTT
87.	FLAG	50	6.92	GLAF
88.	TIRE	99	6.92	RETE
89.	MILK	99	6.92	KLIM
90.	NAIL	50	6.95	NULE*
91.	SHIP	99	6.95	PHIS

	Word	Frequency	Mean Concreteness	Corresponding Nonword
92.	TREE	99	6.97	REET
93.	FORK	31	6.97	FROK
94.	FOOT	99	6.97	TOOF
95.	FROG	25	7.00	GROT
96.	LION	50	7.00	NOIL

Items 1-48 are categorized "abstract"; Items 49-96 are "concrete".

Average Concreteness Rating for "Abstract" Words = 3.1
Average Frequency Rating for "Abstract" Words = 58.5 per million

Average Concreteness Rating for "Abstract" Words = 6.7
Average Frequency Rating for "Abstract" Words = 53.6 per million

According to Thorndike and Lorge (1944)
The higher the value, the higher the perceived concreteness. Max = 7.
One vowel changed from word.